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OF CIVIL ENGINEERS

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Journal of the

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

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Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

POTENTIAL USE OF WATER BY IRRIGATION IN THE HUMID AREA[a]

Keith H. Beauchamp[1]
(Proc. Paper 1750)

The demands for irrigation water throughout the humid area are going to increase greatly in the next 20 to 30 years. Today, irrigation is the greatest single user of water in the United States. Irrigation demands 75 to 100 billion gallons per day, or about one-half of the total fresh water supply used each year. According to the 1950 Census of Agriculture, 94.1% of the country's irrigated land is in the 17 western states, and 5.3% in Arkansas, Louisiana and Florida. The remaining 28 states contain 0.6% of the irrigated land. Based on these figures, irrigation in those 28 states accounts for about one-third of 1% of the water used annually in the entire country. This amount, in total, isn't much today, but what about the future use?

There is a big potential use of water for irrigation in the humid area. It is now increasing at a rate as rapid as that for any other major water use. Humid area irrigation really didn't start until after World War II, except on some truck and vegetable farms, nurseries and by an occasional farmer who realized its potential. The development of light-weight aluminum pipe and quick couplers in 1945 reduced irrigation labor costs and demonstrated that irrigation equipment was practical and could be adapted to many soils and crops. Research results indicated the magnitude of benefits that might be derived from irrigation. Postwar prices of farm products were at a favorable level. Also, the general technological developments in agriculture and farming with more mechanization and more intensification per unit of manpower found a "natural" in irrigation. All of these factors were responsible for the rapid increase in irrigation. This increase is shown by states in Table 1.

Many authorities predict that within the next 20 to 25 years the total consumption of water will double in the United States. Agriculture is expected to use, through irrigation, only 25% over that now used. But, volumewise, this will be many times the amount of water that will go into both domestic and industrial uses. A very large part of this increase will be in the humid area.

Two major factors will influence this expanding use for water by irrigation in the humid area; namely, the ever-increasing need for more food and fibre

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a. Presented at meeting of ASCE, Chicago, Ill., February 27, 1958.

1. Irrig. Engr., Soil Conservation Service, Milwaukee 3, Wis.

TABLE 1

HUMID AREA IRRIGATED ACREAGE

State	Irrigated Acreage 1956*	1949**	Increase 1949 to 1956
Alabama	25,000	367	24,633
Arkansas	892,936	422,107	470,829
Connecticut	20,000	8,088	11,912
Delaware	11,000	474	10,526
Florida	821,282	365,421	455,861
Georgia	80,000	3,161	76,839
Illinois	16,500	1,510	14,990
Indiana	35,000	5,339	29,661
Iowa	22,000	1,386	20,614
Kentucky	18,225	485	17,740
Louisiana	711,000	576,775	134,225
Maine	6,900	4,299	66,701
Maryland	12,000	697	11,303
Massachusetts	19,175	18,507	668
Michigan	24,360	13,901	10,459
Minnesota	28,000	4,235	23,765
Mississippi	157,000	5,086	151,914
Missouri	60,000	2,089	57,911
New Hampshire	1,100	622	478
New Jersey	72,150	28,117	44,033
New York	90,000	19,248	70,752
North Carolina	36,000	2,083	33,917
Ohio	25,000	5,706	19,294
Pennsylvania	21,500	7,251	14,275
Rhode Island	1,009	1,631	- 622
South Carolina	32,000	6,408	25,592
Tennessee	29,000	1,012	27,988
Vermont	689	303	386
Virginia	45,500	2,817	42,683
West Virginia	1,800	40	1,760
Wisconsin	25,000	9,781	15,219
Total	3,341,126	1,516,876	1,824,250

Percentage increase in humid area = 54.6

* Irrigation - Engineering and Maintenance - 1957 Directory and Buyers' Guide Number - August 31, 1957

** U. S. Bureau of Census

on a national level, and the farmer's desire to improve or maintain his standard of living in a period where he finds himself in a temporary squeeze between falling farm prices and static or further increasing costs. The national food and fibre situation in the future will be greatly affected by the rapid increase in population and decrease in available good cropland.

The population of the United States is increasing at a very rapid rate. We now number more than 172 million and are increasing at a rate of around 3 million annually. Assuming this rate of increase to 1975, our population would then be in excess of 228 million. Some authorities predict an increasing rate with a total of 240 million people by 1975. Projecting this population trend to the year 2000, we could have as many as 335 million people living in these United States. (Fig. 1) All of this points to an increasing number of people to feed, clothe and shelter in this country for a long time to come.

Now, let's look at our land picture. The total land area of the United States is 1904 million acres. However, today there are less than 500 million of these acres that can be used for food production, or about 3 acres per person. Projecting this into the future, in 1975 there will be 2.2 acres per person, and by the year 2000, only about 1.6 acres for every man, woman and child.

The nation's cropland acreage is headed downward. Maryland's cropland area has decreased more than 145,000 acres since 1945. Seventy of Iowa's 99 counties reported a decrease in farm land ranging from a few hundred acres to as much as 10,000 acres. Ohio, Indiana, Texas, Georgia and Florida have each had about 1 million acres of arable land diverted to non-agricultural use since 1942; California, South Carolina, Michigan, New York and Oklahoma

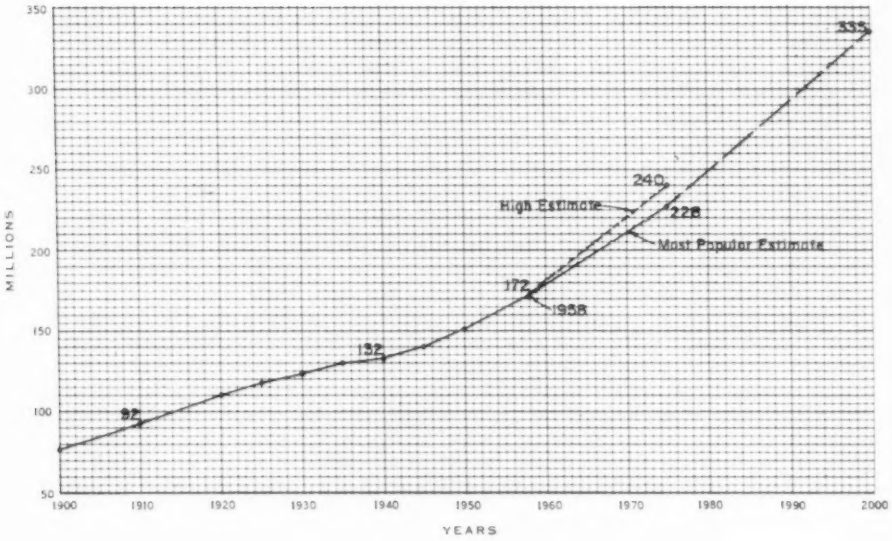
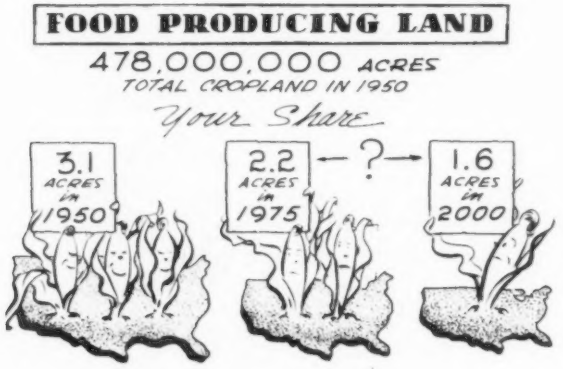


FIG. I U.S. POPULATION

have each had diverted 3/4 of a million to 1 million acres. During the past 15 years, 17 million acres of cropland have been lost to suburban housing, industrial and commercial uses, defense establishments, airports, highways and to other public and private uses. The total average annual cropland losses, including land planted to trees, is 1-1/3 million acres.

Industrial and urban expansion often occurs on good arable land because construction costs are usually lower on level land than on rolling and rocky land. Drainage and water disposal problems are less troublesome. Highway engineers want to avoid grades. Industry likes to move its raw materials in



and its manufactured or processed products out at the lowest possible cost. Airports require miles of level runways and high-speed roadways into the cities. Modern store and factory layouts and suburban developments all require a much larger area of land per person than they did 25 to 30 years ago. Commuters and shoppers require large automobile parking areas, and more emphasis is placed on recreational areas than ever before.

Our super highways require 50 to 60 acres of land per mile. Ordinary first-class highways require about 25 acres or more per mile. The Ohio Turnpike took 16 square miles. The building of the 41,000 mile interstate highway system will, itself, take over 665,000 acres of rural land. A hydrogen bomb plant in South Carolina used 225,000 acres of predominantly farm land. A municipal airport, the size of the Billy Mitchell Airport in Milwaukee, requires 1700 acres, all of which previously was farm land.

Essential non-agricultural developments are necessary for the defense of our country and to keep pace with our expanding population and standard of living. However, policies that will make it possible for our economy to expand without unnecessary encroachment upon our productive cropland need to be developed. Decisions on the location of public and private non-agricultural

developments should be based on the land capability inventories wherever possible.

We are losing land by erosion, floods, alkali, and other forms of land deterioration. Of our present cropland, 121 million acres are subject to a critical rate of soil deterioration. Another 128 million have a serious rate with only 229 million having slight to no soil deterioration. Forty million acres of our present cropland should be in grass and trees.

LAND DETERIORATION

LOSS BY

EROSION - FLOODS - ALIKALI - OTHERS

Increase in tillable lands from reclamation by irrigation and drainage or land clearing and release of present permanent pasture land is estimated at approximately 50 million acres. However, any possible increase in tillable land may be offset by losses due to land deterioration.

As total arable land shifts to other uses and as food demands rise, food production shifts invariably more and more to land less suitable for cultivation. This increases the cost of production. Increased production costs would automatically lower our standard of living for our economy is based on a plentiful supply of food purchasable with such a small part of our expendable income that we have money left over with which to buy the so-called luxuries produced by industry. Food takes only about 1/4 of our expendable income. In many other countries, food takes 30% to 80% and more of the expendable income.

PROBABLE NEW LAND BY RECLAMATION

DRAINAGE *plus* **IRRIGATION**

Equals estimated

50,000,000 ACRES

It has been estimated that the demand on agriculture will be 25% to 40% greater in the next 25 years. (Fig. 2) American farmers are now maintaining in production nearly all land now available to economic crop production and cannot look to much new land to satisfy the nation's future demand for food and fibre. We will have to depend largely on land now being farmed and this land must be made to produce more abundantly. We must protect and build up soil productivity by a complete soil conservation program for every acre in order to sustain these necessary higher yields.

Many authorities feel that technological advances in crop production will be able to keep up with the loss of cropland and our expanding population. Irrigation must and will play its part in making this possible. Sometime ago, the Agricultural Research Service of the Department of Agriculture made a study which revealed two facts highly important to our food problem: (1) In general, the research ceilings of production per acre have leveled off during recent years; (2) There is still a substantial gap of approximately 50% between the level of per unit production possible through full application of science and the actual level of per unit production today on the farms of the nation. This means it is highly important to narrow the gap between average farm yields of today and the yields that could be obtained by the full application of scientific technology.

We have seen three great increases in food production through technological advances. These advances were, first, mechanization of the farm; second, the development of hybrid corn; and third, the expanding use of fertilizers and crop rotations. The next really big increase in the humid area will likely come from irrigation. Only from proper irrigation can we insure that when a man plants a crop, he is going to have enough moisture to harvest it. Irrigation will even out the ups-and-downs in crop yields otherwise due to lack of moisture during some part of the growing season. (Fig. 3) This single factor will be of extreme importance when we reach the time that our food and fibre production equals consumption by our expanding population. When this time comes, we certainly cannot afford to have a loss of food due to droughts.

What is the farmer's attitude here in the humid area toward irrigation? As farm production costs rise and prices level off or fall for commodities, the progressive farmer looks for means of increasing yields and having a margin of profit on each unit produced. Cost of production per acre may increase but it is offset by the higher yields. In the last 10 years there has been a big favorable change in the attitude of the farmer toward a more

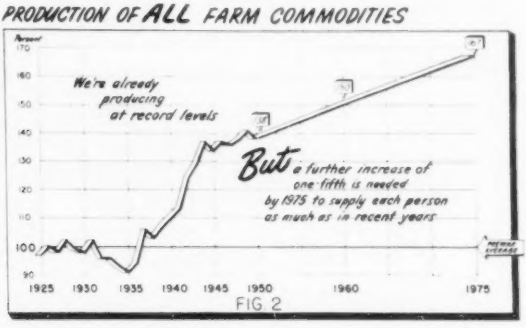


FIG. 2

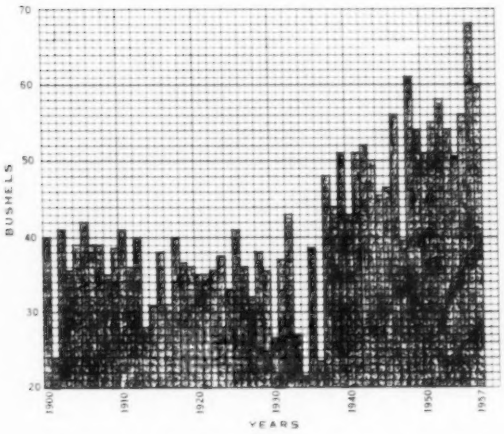


FIG. 3 ILLINOIS AVERAGE CORN YIELDS
(Data from Illinois Agricultural Statistics)

scientific approach to farming. The farmer has seen, through his own experiences and from research results from our universities, that irrigation coupled with good management practices will result in increased yields per acre. He has also found that by maintaining a high level of soil moisture through irrigation he is able to improve the quality of his crop. This is particularly true of fruit and truck crops. Some yield results with irrigation in the humid area are presented in Table 2. Most of these studies were made during years that were unusually favorable for irrigation because of poor distribution of moisture during the growing season.

Lowering cost of production per unit sold is a very important item. Securing the highest optimum yield possible per acre will generally result in a decreased cost per unit of production. This is illustrated in Table 3.

TABLE 2
ADDITIONAL NET INCOME PER ACRE FOR IRRIGATION*
(Experimental Results)

Crop	State	Net Increase in Value Per Acre
Corn	Georgia	$ 62.00
	Virginia	122.40
	Missouri	32.10
Pasture	Tennessee	102.36
	Virginia	96.25
Cotton	Georgia	68.35
	Missouri	242.00
Potatoes	New York	50.96
	Wisconsin	67.00
Sweet Potatoes	Georgia	399.50
Tomatoes	Georgia	133.50
Tobacco	Virginia	282.00

* Max M. Tharp and C. W. Crickman - "Supplemental Irrigation in Humid Areas" -- 1955 Yearbook of Agriculture - Water.

TABLE 3

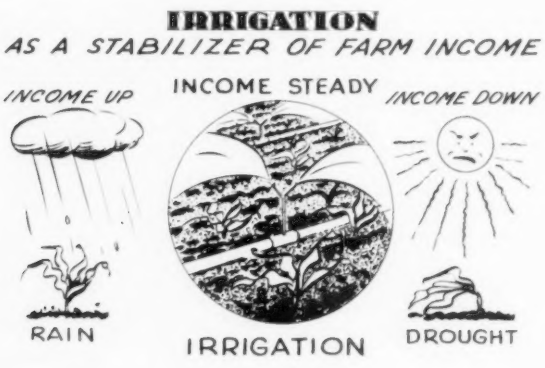
ESTIMATED UNIT COST OF PRODUCTION - CORN
NON-IRRIGATED VS. IRRIGATED

	Per Acre Annual Cost Without Irrigation	Per Acre Annual Cost With Irrigation
Production Average Expected Per Acre	70 bu.	150 bu.
Investment in Land (Average value $400 per acre @ 5% return expected for interest)	$20.00	$20.00
Taxes and Insurance	2.00	3.00
Land Preparation and Cultivation	11.80	11.80
Seed - $12.00 Per Bushel	2.00 (12,000 pop.)	3.50 (20,000 pop.)
Fertilizer	11.80 (160#)	19.70 (250# + plowdown)
Harvesting Including Hauling & Storage	9.40	15.50
Irrigation Costs (Average 3 Times)	-	20.00
Total Cost Per Acre	57.00	93.00
Production Per Acre @ $1.10 per bu.	77.00	165.00
Profit Per Acre	20.00	72.00
Profit Per Bushel	.29	.48
Total Production Cost Per Bushel	.814	.619

Farmers are now beginning to use irrigation as a standard crop production tool, and the farmers who are practicing extensive irrigation plan their farming practices around it. They invest in irrigation to the extent that it gives them a satisfactory return, just as with any other capital expenditure for a farm enterprise. This means, of course, that they either maintain or increase their net farm income.

In addition to increasing crop yields and crop quality, some farmers have found profitable use of irrigation equipment for wind erosion control. It also aids in seed germination. The use for frost protection is becoming a very important phase of irrigation in some areas where such crops as strawberries and certain truck crops are grown. Irrigation systems can also be used for the application of some commercial fertilizers, thereby saving labor costs.

Not only can irrigation help to increase farm income, but it can be a stabilizer of farm income. Droughts, with the resulting lack of adequate soil moisture for crop growth, make ups-and-downs in the farm income from year to year. When the summer rains are adequate and well distributed, the farmer's income may be up. When droughts occur, particularly at the critical



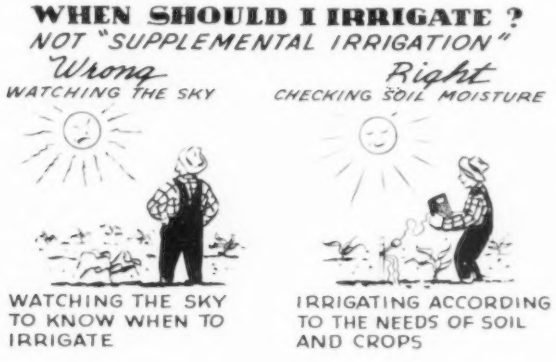
stages of crop growth, then he may lose heavily that year. A steady farm income from year to year is not only desirable for an individual farmer, but is necessary for a stabilized high economy for the entire nation. It follows that when the farm income is noticeably down, industry and labor suffer.

More and more farmers are adapting themselves to irrigation quite readily. Those who have gained experience are also applying water more scientifically. They are watching the soil more than the sky as an indicator of when to apply water. The term "supplemental irrigation" is passing out of the picture in the humid area. The successful irrigator is not using irrigation as a supplementary source of water; he considers rain during the crop growing season supplemental to his irrigation.

Irrigation alone is not a guarantee for successful crop production. Usually it should be the last crop production practice that a farmer uses. In most instances, it is possibly the practice incurring the highest initial investment cost he can use. Advantages from a good soil management program with top level production and no irrigation should be compared with the same program with irrigation in arriving at the irrigation investment decision. In other words, the farmer should consider how far he can go without irrigation in order to properly evaluate its advantages.

A complete soil conservation program should be installed so that a high level of production can be maintained in future years. The highest practical degree of drainage should be provided for the land; effective drainage, both surface and internal, is essential to successful irrigation in the humid area. A good drainage system provides the same results during years of above-normal rainfall that an irrigation system provides for years when rainfall is below normal or poorly distributed during the growing season. A combination of proper crop selection, use of fertilizer, insect control and good farm management will mean more to the farmer than irrigation alone. When all these practices are installed, then through use of irrigation water the farmer can increase the amount of fertilizer that will pay and use a higher plant population to secure increased profitable yields every year.

Although rapid spread of irrigation is predicted in the humid area, the increase in this practice truly will be influenced by climate, prices, market


WHEN SHOULD I IRRIGATE ?
NOT "SUPPLEMENTAL IRRIGATION"
Wrong
WATCHING THE SKY
Right
CHECKING SOIL MOISTURE
WATCHING THE SKY TO KNOW WHEN TO IRRIGATE
IRRIGATING ACCORDING TO THE NEEDS OF SOIL AND CROPS

opportunities, over-all needs for more food and fibre, available water supplies, type of soil, and on the farmers' attitudes.

Farm prices will have an effect on the growth of irrigation, but it is difficult to predict the growth on this basis. Should the margin of profit for farmers go lower, irrigation may well be stimulated. If the farmer can increase his yields economically by irrigation, up to a point he can gain a margin of profit even though prices per unit drop.

Water supplies will be a big factor in influencing the future growth of irrigation. Development of water supplies and distribution to the farm will be the key to the widespread use of irrigation in the humid area.

Future needs for increased food and fibre will have its effect on the spread of irrigation. When the demand for food is great in comparison with supply, the margin of profit for the farmer will be greater.

So-called drought years will tend to speed up the spread of irrigation. Many farmers are prone to purchase irrigation systems and to plan their irrigation on the basis of weather experienced during that year or the preceding year. As the practice of irrigation becomes more widespread, this tendency of irrigating according to precipitation distribution during the preceding year will decrease and most farmers will adopt the more realistic attitude in the future.

Soils in any given area will certainly affect the growth of irrigation. As far as the crop is concerned, a drought depends not only upon the amount of precipitation but also on the type of soil and its management. For example, (Fig. 4) a clay loam soil will hold approximately 2 inches of water available for plant growth per foot of depth; while a sandy loam soil may hold only 1 inch of water per foot. Now, assume that corn is to be grown on each of these two soil types and that 2 feet of soil depth is available to produce the crop. Then the clay loam will be able to store 4 inches of water and the sandy loam 2 inches. At these full storage capacities there will be sufficient moisture during the plants' maximum use period in August, which is approximately 0.3 inches per day, to last 13 days on the clay loam soil and 7 days on the sandy loam without additional water being added.

With irrigation, maximum use can be made of most of our droughty soils. Fig. 5 outlines the approximate extent of droughty soils in the north central

DOMINION OF CANADA
LAKE SUPERIOR
MINNESOTA
WISCONSIN
MICHIGAN
IOWA
ILLINOIS
INDIANA
OHIO
MISSOURI
LEGEND
MOSTLY SANDY SOILS WITH LOW MOISTURE HOLDING CAPACITY AND LOW FERTILITY; CLIMATE AND LACK OF MARKETS MAY LIMIT USE
MOST OF THE SOIL HAS A LOW WATER HOLDING CAPACITY AND FAIR FERTILITY
MOSTLY SANDY SOILS WITH LOW MOISTURE HOLDING CAPACITY AND LOW FERTILITY; NOT LIMITED BY CLIMATE OR MARKETS
GOOD TO HIGHLY PRODUCTIVE SOILS (SILT LOAM LOAMS, AND SANDY LOAMS) WHERE MAXIMUM YIELDS ARE LIMITED BECAUSE OF HOT DRY CLIMATE DURING THE GROWING SEASON
CONTAINS SMALL AREAS OF SOILS WITH LOW MOISTURE HOLDING CAPACITY AND FAIR FERTILITY

Fig.5 GENERAL LOCATION OF DROUTHY SOIL AREAS IN NORTH CENTERAL STATES

states. Food and fibre production could be greatly stepped up in this area and like areas of the humid region through irrigation. Purdue University reported that for 5 years (1948, 1952, 1953, 1954 and 1955) of research at the Purdue Sand Experimental Field, corn yields from 130 to 145 bushels per acre have been produced on plainfield sand by adequate fertilization, proper plant population and irrigation. Long time results without irrigation show a 40-bushel average.

The problem of estimating potential water use for irrigation, therefore, revolves around the estimated increase in the acreage that will be irrigated. The water requirement for irrigated agriculture in inches of water per acre for a given crop on specific soil conditions, in general, are not likely to change to any great extent in future years. Improvement in irrigation efficiencies and adaptation of more desirable crops could even slightly lower the water requirements of crops. The amount of water used by plants varies widely with the kind of plant and with variations in weather, availability of moisture and other conditions. At Manhattan, Kansas, in one study, a single plant of corn used 54 gallons of water during the growing season; a potato plant used 25 gallons; a tomato plant 35 gallons; and winter wheat, 25 gallons. At 54 gallons per plant, an acre of corn at ordinary spacing would transpire 11 inches of water in a season. Additional water would be evaporated directly from the soil. Totalwater requirements for corn range from 19 inches to 29 inches in different parts of the country.

Seldom does a plant have all the water it needs for optimum growth and production in the humid area. Average annual moisture deficiencies in eastern United States are shown in Fig. 6. The water deficiencies given,

Figure 6 - AVERAGE ANNUAL MOISTURE DEFICIT IN INCHES BASED ON DROUGHT DAYS AND SOILS OF 3" WATER HOLDING CAPACITY

however, are only estimates of the average water deficit, and in a hot, dry year, the water deficit could well be double the figures shown. Assuming that 30,000 gallons per acre are required to make up 1 inch of water deficit, the total volume of water required to make up the mean deficit can be estimated. For example, Fig. 6 indicates a deficit of 8 inches for Ohio. If the number of acres irrigated in Ohio increases by 1000 acres, the increase in water use will be about 240 million gallons. Present day use can thus be approximated, and, depending on the increase in the irrigated acreage, future use can be estimated. In using these data, it must be remembered that (1) deficiencies given in Fig. 6 are average annual deficiencies and do not indicate water requirements in extremely dry years; and (2) the total water requirements for the same crop are greater on sandy soils than on clay soils. Thus, water deficiencies in local areas of a state may be higher or lower than the average for the state.

Estimating the number of acres that will be irrigated in the humid area, or in any particular area of that region, depends on so many factors that determining the rate of increase over a short specific period of time can be no more than an educated guess. Many authorities feel that the increase in irrigation in the humid area will be phenomenal in the next 25 to 30 years if adequate water supplies can be made available. I am inclined to share this belief. However, before any accurate predictions can be made on the potential use of water for irrigation in the humid area, thorough studies of crops and soils, potential water supplies, buying power of farmers and long range weather forecasting will be necessary.

Most authorities feel that there will be enough water for everyone provided there is a unified coordination of all water interests to stimulate wise use, development of water resources, and improved efficiency by water users.

Precipitation is the source of our water supply. In the United States our total water supply from precipitation amounts to about 4,300 billion gallons a day. Data by the United States Geological Survey indicates that streamflow derived from surface runoff and ground water amounts to about 8.5 inches a year, or about 1,200 billion gallons a day on the average. This is the potential sustained supply for direct human use in homes, industries, irrigation, recreation, etc. It is about 6 times the average daily use now, and 4 times the predicted requirements in 1975.

Uneven distribution and irregular timing of precipitation complicate our problem of furnishing water when and where we need it. The problem is further complicated with respect to irrigation. Of all the users of water, irrigation accounts for the greatest consumptive use. Whereas 90% of industrial water, 60% to 95% of municipal water, and virtually all water used for power and recreation is returned to surface or underground storage, only 30% to 40% of irrigation water is not evaporated and transpired by crops. Also, the demand for irrigation water is highest when water supplies are at their lowest stage; that is, as hot weather lowers water levels and decreases streamflows, the water demand for irrigation increases.

There is no question but that our water problem in the United States is fast becoming a great challenge to the engineer. We must make every effort to improve water supply systems; to encourage additional water storage in watersheds; to coordinate surface and ground water resources; to survey and study surface water and underground supplies and uses; and in some cases to develop the use of sea water for special uses; and all of these along with provisions for a flexible method of regulation of water use wherever necessary.

Now is the time for the engineer and his co-workers in related fields to plan for the future water needs of this country and irrigation should take its rightful place in this planning. Irrigation is a crop production tool which can be and, no doubt, will be used to maintain our present standard of living in future years.

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WORLDWIDE VIEW OF IRRIGATION DEVELOPMENTS

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(Proc. Paper 1751)

INTRODUCTION

During the first half of the 20th century, the population of the world has increased by 900 million; from 1,600 million in 1900 to 2,500 million in 1950. In the next ten years, not less than 200 million more people will be added to the world population and will have to be provided for. The immensity of the task of feeding and clothing them would be appreciated best if it is noted that this new population will exceed the entire existing population of the North American continent or of the Soviet Union.

In addition to the needs of this new population, it has become increasingly evident, since World War II, that there are large areas—entire countries and continents—where millions of people face eternal famine and eke out a miserable existence. It has also become increasingly clear that the people in the rest of the world, who have better standards of living, can no longer ignore this distress.

The most important thing necessary to feed and clothe adequately the new as well as the old population of the world is the development of water resources, for providing irrigation facilities, to improve existing agriculture and to reclaim large areas of desert or otherwise barren lands.

The increasing industrial development in various parts of the world is also making an ever increasing demand on the available water resources. For example, it takes 65,000 gallons of water to manufacture one ton of steel, several tons of water for a ton of wood pulp, 18 barrels of water to refine a barrel of oil, and about 300 gallons to make a barrel of beer.

The per capita consumption of water for domestic purposes is also rising steadily. Thirty years ago, 50 gallons of water per person was considered adequate in some of the advanced countries of the world. In others, the aim was to get only 30 gallons per capita and in actual fact there were large parts

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where the consumption was not even one quarter as much. These figures have all doubled or trebled by now.

There are other non-consumptive uses of water like navigation, hydro-electric development, fish culture, recreation, etc., which have their own importance in the economic life of people. For large areas of the world, however, irrigation is necessary for survival and the use of water for irrigation, is second in importance only to its use for domestic purposes.

It is proposed in this paper to describe the growth of irrigation developments, various methods of administering and financing irrigation projects, some of the problems that have arisen in connection with irrigation developments and the role of international cooperation in dealing with them.

Irrigation Developments up to End of Nineteenth Century

The first use of irrigation, or the artificial application of natural waters as an aid to agriculture, is older than the recorded history of mankind. Irrigation as a practical art must have begun about the same time as man fashioned himself to a social way of life. History is replete with references to the practice of irrigation from wells, tanks and canals. Even today there are some striking examples of irrigation works built hundreds, and in some cases thousands, of years ago in China, Egypt, India, Iraq, Israel, Italy, and some other countries.

Liping built a multipurpose scheme for flood control and irrigation on the Minkiang River in China 2,200 years ago. Egypt claims to have had the world's oldest dam 355 ft. long and 40 ft. high, built 5,000 years ago, to store water for drinking and irrigation. Basin irrigation introduced on the Nile about 3,300 B.C. still plays an important role in Egyptian agriculture. Irrigation works in the valley of the Euphrates and Tigris must have supported several ancient civilizations in Mesopotamia. Wells, tanks and inundation canals from rivers were well known sources of irrigation water in India thousands of years ago.

While it would be an interesting and fascinating study to fathom deeper into the ancient history of the art and practice of irrigation, it was only towards the middle of the 19th century that construction of large scale irrigation works—a single project to irrigate many hundreds of thousands of acres—became technically feasible. By the end of the 19th century, some of the classic major irrigation works had been built in Egypt, India and other countries and some of the basic difficulties of such development had been tackled and overcome.

Among the notable achievements of the nineteenth century may be mentioned the system of deep canals built in 1826 for the irrigation of Lower Egypt, for the cultivation of cotton, and the Cavour canal built in Italy in 1862 for the irrigation of about half million acres. The developments in India were by far the more impressive. The reconstruction of the old Cauvery Delta system in the south end of the Yamuna Canals in the north were completed in about 1825; the Ganga Canal (now Upper Ganga Canal) was completed in 1854, the Upper Bari Doab and the Sirhind Canals in the Punhab in 1850 and 1873 respectively and the Godavri Delta system in 1890. One of the largest and most successful canals in the world, the Lower Chenab Canal (now in Pakistan), was completed in 1892. This canal alone irrigates annually almost 3 million acres.

There were various other developments of a less spectacular nature in the countries mentioned above as well as in various other countries; the most important of these were numerous small irrigation works built in the United States, in the latter half of the century, all by private enterprise. Among these may be mentioned the efforts of the Mormons in Utah, the Greeley colony in north eastern Colorado and the Anaheim colony in southern California. Taken as a whole, irrigated acreage increased in the United States from about 300,000 acres in 1870 to a respectable figure of 7.5 million acres by 1900.

The major irrigating countries and the acres irrigated in each at the end of the nineteenth century were:

Country	Areas Irrigated Millions of Acres
India (including Pakistan)	40
U. S. A.	7.5
Egypt	6.0
Japan	5.0
Italy	4.0

China also had a large irrigated area mainly from wells, tanks and small canals.

It appears that during the nineteenth century the total irrigated acreage in the world grew from about 20 million acres, at the beginning of the century, to about 100 million acres towards its end. But the more important result of the pioneering efforts in the field of irrigation during the nineteenth century were the advances made in the science of hydraulics and in the technique of planning, constructing and operating large irrigation projects. By the turn of the century, millions of acres of once desert areas had been turned into green fields and gardens, several new villages and towns had come into being and there was new life where there had been none before. Irrigation had emerged as a successful method of increasing agricultural production and of reclaiming the desert for the use of the civilized community.

Growth of Irrigation in the Twentieth Century

The outstanding success of some of the irrigation projects undertaken in the latter half of the previous century opened up new vistas of agricultural development in almost all arid and semi-arid countries of the world. Governments, which in some countries had played only a passive role in the previous century, now began to realize the economic potential which lay in irrigation development; the problems created by the two World Wars provided an inevitable urge towards reclamation and improved agriculture. Irrigation planners began to think in terms of bolder projects—large scale diversions from one river across another to populate waste lands in the distance; medium sized storage projects with dams 100 ft. high or more; large scale pumping of underground waters. Improvements in the use of water, equitable distribution in the entire length of a long canal system, construction of permanent massive barrages on sandy foundations and various other new features opened up horizons for the engineer in his efforts to stall famine and bring civilization to the desert.

After World War I, new types of machinery, new methods of construction, new advances in hydraulics and improved developments in high-dam construction were all brought to bear in the war against the desert. Irrigated acreage increased at a parabolic rate.

The notable achievements during the first half of the present century in the field of irrigation development include:

In Australia, the setting up of the river Murray Commission in 1915;

In Egypt, the completion of the Aswan Dam in 1902 and its subsequent raising in 1912 and again in 1934;

In India, the construction of the Triple Canals Project (now in Pakistan), the Sutlej Valley Project (partly in Pakistan) and the Sukkur Barrage Project (now in Pakistan) each irrigating several millions of acres every year, the Sarda Canal Project, the Mettur and Krishnarajasager dams on the Cauvery;

In Iraq, the Hindiyah Barrage across the Euphrates built in 1913, and the Kut Barrage across the Tigris completed in 1939;

In Mexico, the setting up of the National Irrigation Commission in 1926;

In U. S. A., the enactment of the Reclamation Act in 1902 and the establishment of the Bureau of Reclamation, the Hoover Dam, the Grand Coulee dam and irrigation developments in the Western States.

After World War II, the disparity in the standards of living in different parts of the world became more and more significant, and, for the first time, the world at large came to learn with visible horror, and distress, that there were large areas, entire countries and continents, where millions of people were facing eternal famine. The good in mankind revolted and renewed efforts, both nationally and internationally, began to be made for the increase of food production inter-alia by providing irrigation facilities.

From 100 million acres, at the beginning of the twentieth century, the irrigation acreage by the middle of the century had increased almost threefold to nearly 300 million acres. The efforts being made for further increasing irrigation facilities, in almost every part of the globe, have never been so great as today. Long-range and ambitious plans for the development of irrigation, some in conjunction with other river valley developments, are under way in different countries to meet the challenge of the growing population, to raise the standards of nutrition, to mitigate the effect of drought and to bring security, stability and prosperity to people who depend on lands which either produced only catch crops or no crops at all. It appears that, during the next five years, the total irrigated area in the world would have increased by about 25 per cent and it would be safe to guess that well before the year 2000, the irrigated acreage in the world would have exceeded the 500 million mark.

The Twentieth Century can well be called The Century of Irrigation.

Administration of Irrigation Projects

In general, natural waters belong to the community as a whole and, in most countries, governments exercise varying measure of control over their use in the public interest.

It is also generally recognized that participation of government in one form or another is necessary for optimum exploitation of the water resources for maximum good. In countries like Burma, Ceylon, Egypt, India, and Pakistan, irrigation developments have always taken the form of public works undertaken

Table 1.—World Important New Irrigation Developments Under Way and Areas to be Irrigated in 14 Countries

Country	New Developments	Areas in Millions of Acres
Australia	Snowy River Scheme, and Big Eildon Dam	--
Canada	Various Projects	2.0
Chile	Works under Construction	1.0
China	Restoration of major and minor works and digging of wells	11.8
Egypt	Aswan Dam	2.0
India	Bhakra Nangal Project, Damodar Valley Projects, Hirakud Projects, Rihand Valley Project, and Nagarjunasagar Project	6.0
Italy	Ten Year Program	1.6
Mexico	Miguel Hidalge, and Alto Canal (1953-59)	3.5
Pakistan	Taunsa Barrage Project, Lower Sind Barrage at Kotri, Upper Sind Barrage at Gudu	--
Thailand	Chao Phya, Increasing Irrigation Works (1952-59)	4.8
Turkey	Total Additional Area planned	2.0
U. S. A.	Colombia Basin Project, Central Valley Project, and Missouri Basin Project	Several
U. S. S. R.	Karakuram Canal, North Crimean Canal, Upper Shirvan Canal, South and Central Golodnaya Stepe Canal	2.1
Yugoslavia	Ten-Year Program	1.3

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by the state. Other countries like Australia, Canada and U. S. A., where in the early stages governments only played a passive role in irrigation developments or at best encouraged such developments by individuals, groups of individuals or associations, have since come to appreciate the importance of proper and planned utilization of water resources and have started to assume increasing responsibility for their development. There are, however, a few countries like Uruguay where irrigation is still exclusively private.

Administrative control on irrigation developments is exercised in different countires by (i) the federal government, (ii) state or provincial governments, (iii) authorities, corporations, commissions or control boards appointed by government, (iv) special organizations set up to deal with international rivers, (v) irrigation districts or prefectures, (vi) private agencies of a non-profit or commercial nature.

In Algeria, Burma, Ceylon, Chile, Egypt, Mexico, Philippines, Sudan, Syria, and Thailand, the investigation, design, construction and operation of irrigation works is the responsibility of a technical organization under a Minister.

In Australia, Canada, India, and Pakistan, irrigation is a state or provincial subject and the development of irrigation is primarily the responsibility of State Governments, who have their own irrigation departments. The exceptions are: in Australia, the River Murray Commission administers the development on the inter-State river Murray, and in India, the Damodar Valley Corporation, a semi-autonomous body somewhat on the lines of Tennessee Valley Authority (TVA) in U.S.A. has been set up in connection with the Damodar Valley Project.

In India, the Central Government also has power to legislate on the regulation (direction, coordination and control of works) and development in or on inter-state rivers and river valleys. In view of the magnitude of multipurpose projects and the inability of most of the states to finance them on their own and further to ensure coordinated development in all parts of the country, the Planning Commission in consultation with the central Ministry of Irrigation and Power and the State Government concerned fixes priorities consistent with the funds, material and technical manpower available.

The Central Water and Power Commission of the Government of India is charged with the responsibility of initiating, coordinating and furthering the utilization of water resources for purposes of irrigation, power, navigation and flood control, and for advising on inter-state water disputes.

The Bhakra Dam Project is being constructed by the participating states of Punjab and Rajasthan in their respective territories but a Control Board having representatives of the two states and the Centre is in overall charge of the project. Similar Boards have been set up for the Chambal, Kost, Tungabhadra and Nagarjunsagar Projects. After completion of the projects, the Control Boards will hand over the works to the States concerned for maintenance and operation.

The administration of river valley projects and other irrigation works in China is under the control of the Central Ministry of Water Conservancy. For dealing with the three main river basins viz., the Yellow River Basin, the Huai River Basin, and the Yangtze River Basin, the Central Government has constituted a separate Committee for each. These Committees draw up and construct schemes for the entire river basin covering many provinces. Under each Committee, there are a number of Departments such as General Administration, Engineering, Finance and Political.

In France, several irrigation developments in the 19th century were undertaken by the Societes Concessionnaires (Societies enjoying concessions) with state guarantee of interest. The recent development of the Lower Rhone Basin, through the Compagnie Nationale du Rhone, is essentially a private development under a state-proved plan with a state guarantee of private investment made in the company.

In Italy, the Government encourages the creation of associations for irrigation projects and subsidises the works to be carried out by them: all plans are required to be approved by the Ministry of Public Works. The works carried out by the State are also handed over to the associations on receipt of due indemnity.

In Japan, the Ministry of Agriculture and Forestry is in charge of irrigation and drainage works. Irrigation projects are executed and operated either by the Central or Prefectural Government; smaller works are constructed by farming cooperatives but the Central Government has authority over the works and subsidizes them. In case of multipurpose projects, the activities of the Ministry of Agriculture and Forestry and ther Ministries concerned are coordinated by the Economic Planning Board of the Prime Minister's Office under the direction of the Multipurpose Land (and Water) Development Council. In executing multipurpose projects, each Ministry does its share of the work.

In the U. S. A., there are several types of administrative organizations, private, irrigation districts, state, interstate and Federal.

Private agencies, comprising individual and partnership enterprises, cooperative or mutual enterprises, and commercial enterprises, from their nature cannot undertake very big projects. Nevertheless these agencies have played a significant role in irrigation developments in the U. S. A.

Irrigation Districts are public corporations with power to issue bonds and to contract with the United States Government, or with private agencies, for the construction of irrigation works and to levy taxes on the lands for repayment of the costs of construction and for meeting the costs of operation and maintenance, and are operated by a board of directors elected by the land owners.

Interstate compacts between different states govern the distribution of the waters of some interstate rivers.

Federal coordination of water resources development may be and has been undertaken in two different ways; (i) by creating an agency specially designed for the purpose and (ii) by establishing inter-agency coordination committees, which bring together the several single-purpose federal agencies of national scope.

The Bureau of Reclamation, a Federal Agency, plans, designs and constructs projects, under the Reclamation Act of 1902, and ultimately transfers them to the irrigation districts for operation and maintenance.

In U. S. S. R., the Union Ministry of Agriculture is in overall charge of all irrigation developments in the country. Water Ministries in each Union Republic, subordinate to the Union Ministry of Agriculture, control all the Republican water development organizations. Irrigation projects affecting more than one state or co-operative water utilization enterprises are controlled by the State Water Development organizations. Operation managements of canals of an inter-republican significance are under the Head, Water Department of the Ministry of Agriculture of the U. S. S. R. or, by the order of the latter, under one of the Union Republic Water Ministries. For very large irrigation

systems, operative service of the main canal is organized into a special canal operation management.

Financing of Irrigation Projects

In Egypt, Indonesia, Thailand and U. S. S. R. government assumes full financial obligation for construction and operation costs and re-imburses itself indirectly through excise or other taxes on the produce and through land tax. No water rates are charged the irrigators.

At the other end of the line are the developments in some countries by private financiers with the personal profit motive.

Between these two extremes there are many intermediate patterns.

In Algeria and Morocco, the Government meets the cost of dams which is not reimbursable but the irrigators pay fee for the use of water to cover the maintenance and operation cost of dams and irrigation networks and amortization charges for the latter.

In Australia, Burma, and Italy capital cost of all irrigation works is met by the Government and is non-reimbursable. Returns obtained from water rates are barely sufficient to meet operation and maintenance costs.

In British Guiana, maintenance charges in some places are considered beyond the ability of the cultivator to pay and reduced rates are charged. The Government subsidises by giving annual grants to the Drainage and Irrigation Board which controls irrigation works in the country.

The Government of Canada pays the total cost of construction of the main reservoirs and connecting canals as its non-reimbursable share. The Provincial Governments finance the remaining construction as well as the initial operation and maintenance but their expenditure would eventually be reimbursed wholly or in part by the irrigators.

In China, the general criteria for investment on particular projects seems to be on the basis of maximum benefits to the peasants. The projects are not required to pay any interest to the Government. For the annual maintenance of works, water rates are collected from the peasants and the income is augmented by grants from Government.

In India and Pakistan, irrigation, as a national enterprise, is run on a quasi-commercial basis. The capital cost of a project is financed either from general revenues or from public loans raised in the open market or partly by levy or tax on unearned income through increase in the value of land because of the provision of irrigation facilities. The water users pay water rates per unit area varying with the type of crops and increased land taxes depending on the type of land. These rates are not dependent on the cost of construction and maintenance but have in most cases been able to meet interest on capital and the cost of operation and maintenance.

In Israel and the Philippines, capital and operation costs are met by a charge on water supplied, spread over a number of years.

In Mexico, the Government levies a tax on the lands to be irrigated which is generally less than the cost of providing irrigation. Because farmers recognize the necessity of storage works and public funds are limited, it has been possible to finance parts of the irrigation systems like main canals or distribution systems by direct cooperation from the farmers. In such cases water users either sign contracts for repayment of cost on 2-years or 3-years terms which can be negotiated with some credit institution or they

pledge themselves to buy bonds for the purpose. Water users can use these bonds to pay for contracted obligations or repayment for irrigation works.

In Syria, beneficiaries share the cost of irrigation construction and pay part of the maintenance cost.

Irrigation Projects of the Federal Bureau of Reclamation

In the U. S. A. costs allocated to irrigation, whether in single or multipurpose projects, are reimbursable without interest. In single-purpose projects, the water users through their legally constituted organizations must assume responsibility for repayment of the entire capital cost. In multipurpose projects, the water users must assume responsibility for the capital costs allocated to irrigation by the Federal Bureau unless power development is involved and revenues therefrom are available for repayment of part of the irrigation costs.

Under present procedures, unless otherwise specifically authorized by the Congress, power revenues from multipurpose projects are made available for meeting costs allocated to irrigation only when the lands involved are served from the same multipurpose project. It has been proposed that all such revenues within major basins be pooled and made available for the development of land anywhere within the basin on the basis of the most beneficial use of irrigation water.

It is generally conceded that the benefits resulting from the construction of a project, from the handling and use of agricultural produce and associated intangible benefits, extend well beyond the areas within and immediately adjacent to the projects. In recognition of this, certain States have authorized the establishment of conservancy districts with taxing power to help defray project costs.

In Yugoslavia, irrigation projects are financed out of long term loans from the State National Bank with a low rate of interest. Maintenance expenses are met out of contributions by members of the water associations. If the capital cost and maintenance expenses of a project are too high for the members of the water association and the project is considered important for the country's economy, the Government contributes towards the cost of construction.

Current Problems Relating to Irrigation Development

It has been stated earlier that some of the basic difficulties connected with the development of major irrigation schemes had been overcome by the end of the nineteenth century. The spectacular developments in the field of irrigation during the present century have, however, brought forth many new problems.

In many countries, and on many projects, drainage operations have not kept pace with the development of irrigation. The benefits of drainage are not so clearly apparent as the result of irrigation and Governments have been slow to undertake extensive drainage programmes. It is now universally recognized that every irrigation system must have an adequate drainage system—the more intensive the irrigation the more intensive the drainage system required.

Seepage from canals, irregular distribution of waters, the tendency of farmers to apply large depths of water, and to misuse water, and inefficient

and inadequate drainage have all contributed to a considerable rise in the subsoil water-table on many projects, leading to soil water-logging and sterility.

A general characteristic of soil in all arid and semi-arid countries is the presence of sodium salts in the soils. When the total soluble salt content in the soil exceeds 0.18-0.25 per cent (depending on the clay content), the toxic effect, due to the presence of free sodium salts, reduces crop yield appreciably. Partly on account of the rising water table and partly on account of malirrigation practices, in most arid and semi-arid countries, there is a growing problem caused by accumulation of salts near the surface and in the root zone and consequent deterioration and loss of fertility of irrigated lands.

With the present tempo of irrigation developments, the increasing demand of water for industrial use, and the large increase in municipal requirements, a shortage of water supplies is already being felt in some parts of the world; in many others the problem will become apparent before long. The available water resources in most countries are being fast used up and there is going to be a general competition, not in the distant future, between irrigation and other uses of water. This inter alia calls for the maximum possible economy in the conveyance of irrigation waters from source to the field, and in its use on the farms.

International Commission on Irrigation and Drainage

It was in view of the problem mentioned above, in the context of growing irrigation consciousness in all parts of the world, that the International Commission on Irrigation and Drainage was set up about eight years ago in June 1950. India with its vast developments in the field of irrigation, both past and future, rightly took the initiative in sponsoring this international co-operation. The effort has been more than justified.

In the early history of irrigation development, the engineers in charge were content to learn from their own mistakes, often disastrous and costly. There was considerable duplication of effort, both nationally and internationally, in the development of irrigation technique and connected research. The modern communication system has now brought various parts of the world much closer together and it has been made possible, much more than ever before, for the planner and the designer of water resources development to benefit from the experience gained in the world as a whole. The Commission provides the necessary machinery for this purpose.

The purpose of the International Commission on Irrigation and Drainage is to stimulate and promote the development and application of the science and technique of irrigation, drainage, flood control and river training in the engineering, economic and social aspects.

The Commission has a National Committee in each participating country. Originally set up in 1950, with National Committees in 11 countries, the number of National Committees had by December 1957 increased to 40—a remarkable development in the field of international co-operation. The accompanying map shows the geographic distribution of the National Committees of the Commission.

The International Executive Council, which manages the affairs of the Commission, holds its meetings annually. After the first two meetings in Simla and New Delhi (India), the Council has successively met in Chicago (U. S. A.), Bangalore (India), Algiers (Algeria), Montreux (Switzerland), Madrid (Spain)

Member Countries of the International Commission on Irrigation and Drainage

Table 2.—Member Countries of the International Commission on Irrigation and Drainage

1. Algeria	24. Malaya
2. Australia	25. Mexico
3. Austria	26. Morocco
4. British East Africa	27. Nayasaland
5. British Guiana	28. Netherlands
6. Canada	29. Nigeria
7. Ceylon	30. Pakistan
8. Cyprus	31. Philippines
9. Czechoslovakia	32. Poland
10. Egypt	33. Portugal
11. France	34. Rhodesia
12. French Eq. Africa	35. Spain
13. French West Africa	36. Surinam
14. Greece	37. Switzerland
15. Hungary	38. Syria
16. India	39. Thailand
17. Indonesia	40. Tunisia
18. Iran	41. Turkey
19. Iraq	42. United Kingdom
20. Israel	43. U. S. S. R.
21. Italy	44. U. S. A.
22. Japan	45. West Germany
23. Madagascar	46. Yugoslavia

and San Francisco (U. S. A.). The ninth meeting of the Council will be held in Rome (Italy) in 1958.

The Commission has held three progressively successful Congresses. The first was held in New Delhi in January, 1951, the second in Algiers in April, 1954, and the third in San Francisco in May, 1957. The fourth Congress will be held in Spain in 1960. The transactions of the first congress have been published in two volumes and those of the second Congress in three volumes. The transactions of the third Congress comprising five volumes are under print.

The Commission issues an Annual Bulletin containing articles on the advances made in different countries in the technique and research relating to irrigation and drainage, other statistical data and technical information.

A publication on "Irrigation in the World—A Global Review" has been issued; it contains a brief history of the development of irrigation, description of important projects, administrative set-up and methods of financing, etc., in about 60 countries of the world.

The Central Office of the Commission brings out regularly, starting from 1957, an annual bibliography of the literature relating to irrigation and drainage, published in different member countries.

The Commission has also prepared, as part of a multilingual technical dictionary on irrigation and drainage, definitions with illustrations, where required, of over 2,100 technical terms; further work is in progress.

The Central Office of the Commission maintains a technical library on irrigation and drainage engineering and allied subjects and arranges interchange of publications between its various National Committees.

The Council has recently approved that studies and experiments on conservation and economical use of water supplies and on other subjects of interest be organized by the Commission with the help of its National Committees. The Research Planning Committee, appointed by the Council, has decided that, in the first instance, studies and experiments be carried out on the following two subjects:

(1) Methods to reduce evaporation losses from water surfaces such as storage reservoirs and tanks.
(2) Consumptive use of water for sugar cane, rice, wheat and cotton under different soil and climatic conditions.

Through the whole-hearted cooperation of its National Committees the Commission is progressively endeavoring to perform the task undertaken by it.

The Commission is a founder member of the Union of International Engineering Organizations set up in October 1950, and has received considerable support through it from UNESCO. The Commission participates in the meetings of the Advisory Committee on Arid Zone Research.

The Commission was granted Consultative Status "B" by the Economic and Social Council of the United Nations in April, 1954, and special Consultative Status by the Food and Agricultural Organization in November, 1955.

Special Problems Relating to International Rivers

Reference has been made in the preceding pages to the shortage of water supplies in meeting the combined requirements of irrigation, industry and municipal uses which is already being felt in some countries and which is likely to become apparent in others before long. The competition between different types of uses has also been mentioned. The solution of these problems, difficult as it is, becomes all the more difficult on international rivers. As world population continues to grow, and there is an increasing urge towards improved standards of living, different countries are getting more and more interested in their vital water supplies and international rivalries are on the increase.

Treaties and agreements between nations, developed on the basis of fact and understanding, are the only solution of this problem. Nationalistic tendencies and sometimes deep-rooted prejudices, however, are difficult hurdles to cross.

Even within a country, within the same economic unit, questions relating to water rights present considerable difficulty in their solution; much more so when the conflicting interests are represented by two or more different political and economic units.

Currently, two international organizations, the Institute De Droit Internationale and the International Law Association, have taken upon themselves the task of proposing some general principles which, in their view, all the nations of the world should accept for settlement of their respective rights in the waters of international rivers.

It is to be hoped that the principles which they would put forward would take due account of the ever-improving engineering techniques and the ever-increasing demands on the use of available water resources for agricultural, industrial and other purposes. If the principles to be evolved by these bodies do not, for any reason, take due note of these factors and are in the nature of rigid rules based on an incorrect or incomplete appreciation of modern technical developments, they would defeat the very purpose for which they are being formulated. Not only will such principles not be acceptable to various Governments but they might also, because of their rigidity or incomplete consideration of technical developments, create additional artificial barriers in the way of agreement between nations. Since it is only by these agreements that these disputes can be resolved under the present political structure of the world, the general principles to be evolved must take due note of modern technical developments and varying social needs in different countries.

It is, therefore, for the International Commission on Irrigation and Drainage, its various National Committees and other bodies interested in irrigation development like the Irrigation and Drainage Division of the American Society of Civil Engineers to apprise these eminent legal bodies of the nature of technical problems to be dealt with, and of their diversity in different parts of the world and thus to assist them in the task that they have undertaken.

As a first step, towards assisting in developments on international rivers, the Executive Council of the International Commission on Irrigation and Drainage, decided at its meeting in San Francisco that the Central Office of the Commission, with the help of its National Committees, should publish a compendium of all the existing treaties with regard to the use of the waters of international rivers, together with relevant technical information. Work in other fields is also necessary and it is hoped that the International Executive Council will seize itself of the problem; its solution requires a degree of objectivity, forbearance and appreciation of the "other man's need" much more than is found in the political history of the world.

Paper 1752 September, 1958 IR 3

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MULTIPLE-USE PROJECTS IN DEVELOPMENT OF WATER RESOURCES[a]

W. A. Dexheimer,[1] M. ASCE
(Proc. Paper 1752)

The basic requirement of our economy that some of us are, and all of us should be concerned with, is that of supplying water, food, goods and services to our people. Man must have these things and we, as civil engineers, must plan and construct the water works, sewage plants, highways, airports, and industrial capacity to meet our needs.

In connection with the supplying of these goods and services, there is an explosive force more important and one with greater potential impact than all others—the expanding world population.

The most heavily populated areas of the world are gaining population at rates of 1 or 2 per cent per year—they are already crowded and hungry. They are literally bursting at the seams. Such conditions breed discontent and discontent breeds trouble. If this increase continues at the present rate, it will aggravate the present world-wide maladjustment. Only by increased production of food and fibre can this situation be alleviated.

This is being accomplished in some foreign countries by greater diversified use of their rivers. Water is the lifeblood of nations. India, Russia and China are building many multi-purpose river basin projects.

To meet the demands of our own expanding population and economy and to promote a continuing high level of national prosperity, it is essential that our water resources be protected, developed and utilized simultaneously for many purposes.

Conservative estimates indicate the United States will have 220 million people by 1975—an increase of 50 million in 17 years. If we are to provide essential water for our future needs, we must plan and build every new project on a basis of getting the maximum use of water.

The Bureau of Reclamation as an agency of the Department of the Interior, has pioneered and built multipurpose developments in the western United States. Relatively unhampered by riparian restrictions and working under a system of beneficial use for the many, we have gone forward with development to the greatest extent consistent with present needs and for those we anticipate

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a. Presented at the February 1958 ASCE Convention in Chicago, Ill.

1. Commissioner of Reclamation.

to serve future generations. In this work we have been joined cooperatively by other Department of the Interior agencies; the Corps of Engineers of United States Army; the Department of Agriculture; and many other Federal, State and local organizations.

In its work in the West it is the general objective of the Bureau to achieve the maximum sustained use of the surface water and ground-water supplies consistent with sound economic and engineering principles. The irrigation phase of the Bureau's work is primarily that of reclaiming arid land in the West. Flood control, which goes hand-in-hand with conservation of water, is aimed at safeguarding life and property—and promoting economic stability. By judicious use of snow surveys and runoff forecasts, we are able to overlap flood control and conservation storage to a considerable degree in Reclamation reservoirs.

These objectives and policies—along with the planning for hydroelectric power production, municipal and industrial water supply, navigation, fish and wildlife propagation, recreation, pollution control, sediment control, land drainage, and salinity control—provide the basis for our present-day concept of basin-wide development.

The lack of a dependable supply of water at times when it is most urgently needed results in keen competition among different types of use, such as municipal and industrial water, irrigation and power. We seek to fill as many of these needs as possible as well as using the water over and over again for the same purpose.

The Bureau plans for the development of any project take into account State laws governing water use. To facilitate the equitable distribution of an insufficient water supply, all 17 Western States have adopted statutes which recognize, to a greater or lesser degree, the doctrine of prior appropriation.

The basic principle of this doctrine is that the first person in point of time to put the water to a beneficial use is acknowledged to be the first in right. A greater refinement and clarification of this principle would be helpful in multipurpose basin-wide development.

The constitutions or statute laws of many Western States specify that, among the various needs, domestic use shall have first preference, and agricultural use shall have preference over use for water power and manufacturing.

Some states also recognize the common-law doctrine of riparian rights, under which an owner of land contiguous to a natural water course is entitled, at any time, to use water for domestic purposes and for such irrigation of contiguous land as is reasonable in relation to similar requirements of other riparian users from the same stream. This latter doctrine is not conducive to multipurpose use of the water and is a stumbling block to development work, particularly in the eastern part of the country.

Much has been accomplished in the Western States in water resource development even under these conditions. It is worth our while to review the principles underlying reclamation programs and the purposes served.

In general, no use or purpose is included in a Federal project unless the benefit to be derived exceeds the cost of providing it. This may be a negative approach, especially where preservation of fish, wildlife, scenic and historic values are involved. Nevertheless the cost allocated to a use should be not less than the incremental cost of including the purpose in the project, nor more than the alternative justifiable expenditure which would provide the same benefit. If the costs allocated are reimbursable, the recipients of the

benefits should pay the additional costs of operation and maintenance and a fair share of the project costs. However, it is not always that simple.

Most of the simple and relatively inexpensive irrigation projects in the western United States have already been built. These are usually compact geographically and relatively simple in operation. As a result, many new projects must of necessity take in a wide geographical area. Many if not most of these new projects as well as those now under investigation or considered for construction by the Bureau of Reclamation, have costs allocated to irrigation greater than the water users are able to carry.

However, because of the proved value of reclamation development, Congress has made provision on many projects for the repayment of the balance of the cost allocated to irrigation from net power revenues. This usually occurs after the cost allocated to commercial power is returned with interest to the Federal Treasury. Net revenues from the sale of municipal water are similarly used on occasion to assist in paying irrigation costs which are beyond the repayment capacity of the irrigators.

Thus hydroelectric power plants are a very important part of multipurpose reclamation projects. It would be wasteful not to utilize the available energy. The irrigation and power add to the economic development of the entire area and the Nation.

Power features are planned, designed and operated so that energy generation does not preclude optimum economic use of water for other purposes, particularly the preferential uses for domestic and municipal supply and for irrigation.

The Reclamation Project Act of 1939 provides general authorization for allocation of construction costs to municipal water supply and similar purposes, provided such costs can be returned with interest to the United States.

The laws of most States recognize that human consumption has first preference among water users, as it obviously should. Consequently the supply of water for municipal works is of primary importance in relation to other water supply matters.

When planning multipurpose projects, we do not overlook any possibility of providing additional services—such as navigation—which might increase the total benefits of a project without interfering appreciably with its primary purpose.

Where fishery resources are involved, the Bureau seeks to provide measures to protect and enhance fish life, insofar as practicable. This is accomplished by installing fish ladders to permit migratory fish to pass dams, installing screens to exclude fish from irrigation canals, releasing water as necessary to maintain fish life and constructing fish hatcheries to replace natural spawning areas for anadromous fish damaged or destroyed by project works.

Recreational facilities such as boating, swimming, picnicking, and camping provided cooperatively with groups or States attract more people than would otherwise visit the project area. Last year more than 10 million people visited Reclamation projects for recreation purposes.

An ever-increasing problem in water resource development is pollution by sewage, industrial wastes, and other sources. Pollution is of particular concern where municipal water supplies and water for recreational purposes are contemplated.

Reclamation projects also are affected by the quality of water supply available, primarily in connection with the suitability of the water from the

standpoint of its effect upon the soil and the growth of irrigated crops. Project works may be detrimentally affected by deposition of waste products in reservoirs and canals and by chemical action of wastes on structures, control works, and equipment.

The effects of sewage and industrial wastes upon recreational uses of the watershed may justify pollution control measures. Pollution of waters used for bathing, fishing, boating, or as major recreational features, may cause tangible damage and—even more significant—intangible harm. Conversely, reduction of existing pollution may create such recreational opportunities.

Sediment control is essential to the preservation of the capacity of a multiple-purpose project. Sediment control is of primary importance in irrigation operation and may be provided by desilting works to reduce sediment inflow to project canals and by providing extra capacity in reservoirs to offset the encroachment of sediment on conservation capacity.

Together with irrigation, drainage is a major factor in land reclamation and hence an important element in water resource development. Land drainage in the West is the seeming paradox of removal of excess water from agricultural lands to enable irrigation to be practiced successfully and perpetually. It is necessary, of course, to prevent water-logging, accumulation of harmful amounts of salts, deterioration of soil structure, and flood damages to project or non-project properties.

As irrigation spreads in other parts of the country we may well expect the aggravation of existing drainage problems or the discovery of new ones, if adequate provision is not made in the design and construction of facilities for removal of excess waters.

Salinity control includes the use of water low in dissolved solids to dilute waters of higher salt content, provision of valley outflow sufficient to repel saline encroachment in areas affected by tides, and recharging depleted ground-water reservoirs subject to pollution by salt water invasion. These objectives are achieved by additional releases of stored fresh waters, and have benefits beyond the immediate project area.

Water high in dissolved salts in seacoast areas can also be controlled by other means of exclusion, such as by structural or fresh-water barriers to prevent encroachment of the sea water, by ponding and evaporation of small amounts of highly saline surface water, or by return of saline surface water to ground-water basins which are already polluted. Mildly saline or brackish waters can sometimes be treated economically to remove the salts making the water suitable for irrigation, municipal, or industrial uses.

In this latter field, the Department of the Interior's Office of Saline Water is obtaining promising results in its research on economic means of desalting saline or brackish water for irrigation and other use.

Salinity control goes beyond water alone to include maintenance of a satisfactory saline balance in soils by application of sufficient quantities of water and provision of necessary drainage facilities to assure an adequate outflow of salts from individual farms and from project and valley areas.

In the arid West, a means of reducing evaporation from lakes, reservoirs, and canals could be of major economic importance. Annual water losses from evaporation alone range up to 8 feet of depth on western reservoirs, equivalent to 6,000,000 acre-feet of water.

The Bureau, in cooperation with other public and private agencies, has been experimenting in the use of hexadecanol to reduce evaporation. This harmless, odorless, tasteless chemical quickly spreads across a water

surface "locking in" water molecules. Promising results have been obtained on small ponds and experiments are now under way on larger reservoirs. Effectiveness on large reservoirs will be primarily determined by the ability to maintain a monomolecular layer of the chemical on a large surface area where wave and wind action tend to break up the film. We hope it may soon be possible economically to effect savings of 30 per cent or more in evaporation from reservoirs.

Here, in sketch form, is the basic framework which guides the Bureau of Reclamation in planning the integration of water uses in the multiple-purpose development of a river basin in the Western States. Let me emphasize that each basin or project presents its own problems which must be resolved within this framework to effect the optimum economic use of the available water. But as you can see, a multiple-purpose project provides widespread benefits far beyond the basic purpose of irrigation, storage or flood control.

There is a great challenge to engineers in the Eastern half of the Nation in multipurpose planning for the most beneficial use of its water supply. Need I remind you of what is happening in our eastern watersheds?

Consider the alarming drop in ground-water in the mid-West and parts of the East and the concern over the dependability of this supply. Drainage of lands, channelization and the effect of mushrooming expansion of acres of impervious roofs of homes and paved streets and roads has caused quick runoff. There is less opportunity for ground-water replenishment in areas where it is needed the most. This situation is aggravated by the consuming thirst of many new industries which tap this source for high quantities for industrial use.

Consider the greater quantities of municipal and industrial waste which are so conveniently disposed of in natural channels. Pollution of our potable supplies in densely populated areas is a serious problem which the engineers of the Public Health Service and the state and local governments are fighting hard to overcome.

Consider the torrential rains which are quickly carried off as drainage. You could say as you watched a flood-swollen stream: "There goes my water supply for next year."

You should not overlook the color of the flood water as it tumbles by. That turgid look comes from someone's top soil. Also remind yourself that what you see is energy being wasted in a brisk trip to the sea.

Consider too that last month's flood flow may be well out to sea and not available to quench the need of thirsty crops and orchards.

There is a great opportunity here then for the civil engineers in the eastern half of the country to profit by the experience of the Bureau of Reclamation, the Corps of Engineers and other Federal, State and private engineering firms who are working together to develop full use of the limited water resources in the western states. By extending to other areas of the Nation the basic principles that have come out of multipurpose river development in the West, we can take a major step forward to meet the forthcoming water crisis that appears to be inevitable.

The State of Virginia and other states are considering modification of their laws on water rights in recognition of the increasing need for full utilization of the available water. Irrigation is becoming recognized as one useful purpose in the East and South, along with the many others.

The great challenge still lies before us. It is when we look to the future that the concept of river basin planning, construction and operation becomes

critically important. Here in the United States with its population increasing at the rate of three million a year—30 million or more a decade—perhaps 50 million in the time it takes to plan and build a large multipurpose project, we cannot long delay.

Our daily rate of water use is now more than 200 billion gallons but will double by 1975. What must we do to meet this need? Will multipurpose basin-wide planning and construction do it?

It will do more than any other approach to the problem if we broaden our thinking and objectives along these lines:

1. Revise our state water codes where necessary to permit maximum development and multi-use of water resources throughout the country.
2. Include long range capacity for tomorrow in facilities being built to meet today's needs.
3. Recognize recreation and fish and wildlife values in our rivers and streams as they exist today, making an honest effort to retain these values to the greatest degree possible and, conversely, give honest recognition to the conservation interests in analyzing the necessity for water development projects, inviting their participation and cooperation in planning for adequate protection or replacement and enhancement of these resources.
4. Evaluate existing single purpose projects to determine how they may be best utilized in a multipurpose basin concept of operation.
5. Recognize that no one agency, public or private, and no one unit of government, local, state, or Federal, can or should undertake the total development but that each must consider the total need in any project planning.
6. Prepare coordinated programs for river basins enlisting State participation and using funds available for public works planning so that a blueprint is worked out to provide for future construction to proceed in an orderly manner towards the agreed-upon goal necessary to supply the tremendous demands of the next two decades.
7. Establish a democratically constituted and selected agency to coordinate planning and operation of individual units in a river basin within the framework of maximum multipurpose development.

As you can judge from this summary, the path of multipurpose basin development is not without obstacles. In the final analysis, most of these obstacles are created by the inability to see more than one's own particular water needs.

As engineers and those having primary responsibility for keeping our water supply ahead of demand, we must not confine our thinking to the design and construction of physical structures. We must keep in mind the importance of public understanding and acceptance of the measures which are necessary if we are to realize the greatest benefits from our available water resources.

Only then can we hope for success in meeting the country's water needs.

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STATE VERSUS FEDERAL CONTROL OF WESTERN WATERS

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(Proc. Paper 1753)

The 1955 decision of the United States Supreme Court in the Pelton Dam case is a serious threat to the sovereignty of the western (reclamation states over the control of non-navigable waters within their borders. Congress has repeatedly affirmed such sovereignty and must again do so in terms which cannot be misconstrued.

The gradual encroachment by some departments and agencies of the federal government on the rights of the states to control the appropriation and use of non-navigable waters is causing great concern among the reclamation states. The assumption of federal jurisdiction over inland streams and waters seems to be in violation of the many acts of Congress which have stated in no uncertain terms that the federal agencies must comply with state laws relating to the appropriation of water. The matter must be resolved into either federal control on the one hand or a continuation of state supervision and control on the other.

The law of prior appropriation of water originated among the miners of California in the earliest days of that state, and it has been copied in most of the western states. Rights to the water came with the acquisition of title to the lands by the United States. There has been some discussion as to the origin of our title to what was known as the "Oregon Country," and there is a question whether such title was derived from the Louisiana Purchase or directly by discovery and prior possession. At any rate, the map of the United States issued by the General Land Office states that the title was established in 1846.

The earliest water laws grew out of customs of these California miners and the rules they adopted at mass meetings. These rules covered a wide

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1. State Engr. of Oregon.

field of law but were devoted specifically to property rights. Their fundamental principle held the natural resources to be free to all, the first possessor being protected. The rule, "First come, first served," was applied by common acceptance.

As the use of large quantities of water became essential to mining operations, it became one of the mining customs or regulations that the right to a definite quantity of water and to divert it from streams or lakes could be acquired by prior appropriation. Historically, the law of appropriation of water is merely a branch of mining law. It was only an extension of the same rule as that by which possession of mining claims was recognized.

When the state courts were organized and received the questions growing out of these appropriations of water by the miners, the necessity was thrown upon the court of giving legitimacy in some way to these things that had transpired and were so firmly established. There was an immediate conflict of contentions. This conflict existed along two distinct grounds. One was the relation of these new rules to the common law which, in general, as it applies to water, is the so-called riparian doctrine. The other was of the relation of the appropriators to the United States government, the landowner of the region that the pioneers were appropriating to themselves without federal authorization. The first was a question of local law; the second, a question of federal public land law.

For 18 years, from 1848 to 1866, the local regulations and customs, as enforced and molded by the state courts and implemented by state legislation, constituted the law governing all property in minerals and water on the public lands. The system was basically good, and Congress recognized that fact. Its recognition in legislative form became the act of July 28, 1866, declaring that mineral lands of the public domain were free and open to exploration and occupation, and providing that water rights which were vested and accrued by priority of possession under local customs, laws, and decisions should be federally recognized and protected.

The possessory rights vested by the 1866 act were further extended and protected by Congress in the act of July 9, 1870. Mr. Justice Sutherland of the United States Supreme Court stated that the effect of these two acts was not limited to rights acquired before 1866. "They reach into the future as well," he said, "and approve and confirm the policy of appropriation for a beneficial use, as recognized by local rules and customs, and the legislation and judicial decisions of the arid-land states, as the test and measure of private rights in and to the non-navigable waters of the public domain."

In the Desert Land Act of March 3, 1877, which was applicable to eleven states and potential states, Congress specified that all surplus non-navigable waters, over and above bona fide prior appropriations, should remain free for the appropriation and use of the public for irrigation, mining, and manufacturing purposes. Mr. Justice Sutherland said that if the language of this act was to be given its natural meaning, and the Supreme Court at that time saw no reason why it should not be given that meaning, it effected a severance of all non-navigable waters upon the public domain, not theretofore appropriated, from the land itself and made such waters available for appropriation under state laws.

As stated in the opening paragraph, there seems to be a conflict between the desires and intent of the Congress, as evidenced by many pieces of legislation, and the decisions of the United States Supreme Court. The Congress has stated over and over again that federal agencies must comply with state

laws in the appropriation and use of water. The Supreme Court gives no weight whatever to these acts of Congress, but bases its rulings on its own interpretations of the United States Constitution, particularly the commerce clause. The commerce clause as set forth in Article I, Section 8, states that Congress shall have power "To regulate commerce with foreign nations, and among the several states, and with the Indian tribes." By its ever-broadening interpretations of this clause, the court has held that the federal government has the paramount right to control navigable streams, or streams which can be made navigable by artificial means, or streams which in themselves are non-navigable but which flow into navigable waters—all regardless that there may be no possibility of use of these streams in interstate or foreign commerce or commerce with Indian tribes.

In plain language, which expresses the views of many, perhaps all of the western states, Congress on the one hand is trying to preserve the rights of the states to control and regulate the appropriation and use of water, and the Supreme Court, on the other hand, appears to be placing arbitrary and unfair interpretations on the commerce clause of the Constitution in order to keep the paramount control of western waters in the United States.

As an illustration of the intent of the Congress, the thoughtful reader should look at the language of some of the important pieces of legislation, beginning with the Reclamation Act of 1902. Section 8 of that act provides:

> "That nothing in this Act shall be construed as affecting or intended to affect or to in any way interfere with the laws of any State or Territory relating to the control, appropriation, use or distribution of water used in irrigation, or any vested right acquired thereunder, and the Secretary of the Interior, in carrying out the provisions of this Act, shall proceed in conformity with such laws, and nothing herein shall in any way affect any right of any State or of the Federal Government or of any landowner, appropriator, or user of water in, to or from any interstate stream or the waters thereof: Provided, that the right to the use of water acquired under the provisions of this act shall be appurtenant to the land irrigated, and beneficial use shall be the basis, the measure, and the limit of the right."

Section 9(b) of the Federal Power Act requires that an applicant to the Federal Power Commission for a license shall submit to the Commission

> "Satisfactory evidence that the applicant has complied with the requirements of the laws of the State or States within which the proposed project is to be located with respect to bed and banks and to the appropriation, diversion and use of water for power purposes . . ."

Section 27 of the Federal Power Act reads:

> "That nothing herein contained shall be construed as affecting or intending to affect or in any way to interfere with the laws of the respective states relating to the control, appropriation, use or distribution of water used in irrigation or for municipal or other uses, or any vested right acquired therein."

Probably the worst single setback to the rights of the states to control the distribution and use of water was the Pelton decision of the United States Supreme Court on June 6, 1955. (Official title of the case is Federal Power Commission v. State of Oregon, 75 S. Ct. 832) In this decision the Supreme Court upheld the authority of the Federal Power Commission to issue a

license for a major hydroelectric project on Deschutes River, Oregon, even though no water right for the project had been granted by the state. It held that it was not necessary for the applicant for federal license to even apply to the state for a water right.

The Deschutes River is a non-navigable tributary of the Columbia River and is entirely within the State of Oregon. An application for a license for a project on this stream was made to the Federal Power Commission in 1949, and the applicant also applied to the Hydroelectric Commission of Oregon for a state license. The Oregon Commission refused to issue a license because, as a condition precedent to construction, it was necessary under an Oregon statute that permission be granted by the Oregon State Fish Commission. The applicant and the Fish Commission could not or did not agree upon the measures necessary for protection of the runs of anadromous fish in the stream.

Following this, and notwithstanding that the applicant did not have permission of the state, the Federal Power Commission issued a license for the project. A rehearing being denied, the state sought a review by the Court of Appeals for the Ninth Circuit. That court set aside the Federal Power Commission's order granting the license. (211 F. 2d 347) It held that Congress, by its public lands legislation, long ago had transferred to the State of Oregon such control of the use of non-navigable waters and that the applicant must secure permission of the state.

The United States Supreme Court granted certiorari and reversed the Ninth Circuit Court of Appeals. While confirming many previous decisions that the state had control of the use of water on public lands, it held that the lands here involved were reserved lands as distinguished from public lands. The court said,

> "The lands before us in this case are not 'public lands' but 'reservations'. Even without that express restriction of the Desert Land Act to sources of water supply on public lands, these Acts would not apply to reserved lands."

The Pelton decision, considered separately and as applied to only the Deschutes River, would have no very serious consequences. There was a difference of opinion among the people of Oregon as to whether the project should be built, some holding that the Deschutes River in this location is more valuable as a fishing and recreational stream and for the passage and spawning of anadromous fish, and others maintaining that the recreational possibilities would be enhanced by construction of the project. Regardless of the merits, the decision is critical as it affects the control by the state of waters of many other streams on which there are federal power site reservations. A map of Oregon on which these reservations are marked shows that practically every potential power site has been reserved. There is also the question not completely answered by the decision as to whether it applies to reserved lands in the national forests and Indian reservations.

The State of Oregon has been complacent through the years, with the firm conviction that it would have complete control over the rights to appropriate water for beneficial use and the further right to say whether or not power developments should be permitted on any particular stream. The state has from time to time withdrawn certain waters from appropriation for power, holding that certain streams were more valuable for fish and recreation than for power. As examples, consider Multnomah Creek, which forms Multnomah

Falls, withdrawn from appropriation by the legislature many years ago in order to preserve the falls as a nationally known scenic attraction. Also, many years ago, it withdrew the Rogue River from appropriation for power purposes, prohibiting construction of dams in this region below a designated point. In the section of the stream withdrawn, there are several power site reservations. If this Pelton decision is to be the law, the Federal Power Commission could license hydroelectric projects on Multnomah Creek and on this withdrawn section of the Rogue River, and such projects could be built, notwithstanding the protests of the state.

It appears clear that the Congress in enacting the Federal Power Act very clearly expressed its intention that water rights for any project licensed by the Federal Power Commission must have approval by the state.

Nothing can be gained by merely criticizing the decision of the United States Supreme Court. The only possible way of obtaining corrective action is through new legislation by Congress stating in no uncertain terms that any license issued by the Federal Power Commission shall not be effective unless and until the licensee has obtained permission from the state or states in which the project is located.

Many authorities on Western water law have pointed out what seems to be a fallacy in the Supreme Court decision. While reconfirming the court's many decisions holding that the state has full control of water on the public lands, it goes on to state that "these are not public lands." But the court apparently ignored the fact that they were public lands when the Desert Land Act was passed in 1877. It did not explain how the President by executive order in 1910 could take back the control of water which was separated from the land by the Congress in 1877. If the Department of the Interior has that authority, it could now reserve all of the remaining public lands along all streams and, by so doing, completely deprive the state of any control of the waters on, or running through, these public lands.

Following are some quotations from the dissenting opinion of Mr. Justice Douglas, which is printed along with the Supreme Court decision of June 6, 1955. Justice Douglas expresses in clear and concise language the concepts the states must make definite and strengthen by new legislation. He said,

> "I would not suppose the United States could erect a dam on this nonnavigable river without obtaining its water rights in accordance with state law. If I am right in that assumption, then this dam cannot be built without satisfying Oregon's water-rights law. For the federal licensee who will build this dam acquires all its rights from the United States. And the United States cannot give what it does not have."

He went on to say,

> "Oregon's position has for its support two other decisions of this Court, both construing the Desert Land Act. The first of these is California Oregon Power Co. v. Cement Co., 295 U.S. 142, which construed the provision of the Desert Land Act, crucial here, which reads: 'all surplus water over and above such actual appropriation and use, together with the water of all lakes, rivers and other sources of water supply upon the public lands and not navigable, shall remain and be held free for the appropriation and use of the public for irrigation, mining and manufacturing purposes subject to existing rights.'

"The Court interpreted that provision as follows: 'The fair construction of the provision now under review is that Congress intended to establish the rule that for the future the lands should be patented separately; and that all non-navigable waters thereon should be reserved for the use of the public under the laws of the states and territories named.' (295 U. S. 142, 162)

"That case, to be sure, involved a contest between private owners. But the principle announced was shortly applied to the United States as a property owner on a non-navigable stream. In Ickes v. Fox, 300 U. S. 82, the Court held that by the Desert Land Act 'if not before, Congress has severed the land and waters constituting the public domain and established the rule that for the future the land should be patented separately. Acquisition of the government title to a parcel of land was not to carry with it a water-right; but all non-navigable waters were reserved for the use of the public under the laws of the various arid-land states.' (Id., 95)

"The Fox case involved water rights of farmers under a federal irrigation project, the claim being that the United States, owner of the irrigation system, owned the water rights. The Court rejected that claim and looked to state law to determine who had the water rights; and finding that the farmers owned them, the Court held that the United States was not an indispensable party in litigation concerning them.

"Those cases should control here. The Desert Land Act applies to 'public lands'; and the Federal Power Act, 41 Stat. 1063, as amended, 16 U.S.C. Sec. 791a et seq., grants the Commission authority to issue licenses for power development 'upon any part of the public lands and reservations of the United States,' Sec. 4(e). The definition of those terms in the Act says nothing about water rights. And, as I have pointed out, it has been the long-term policy of Congress to separate western land from water rights.

"The final resort of the Commission is to the Act of June 25, 1910, 36 Stat. 847, providing: 'That the President may, at any time in his discretion, temporarily withdraw from settlement, location, sale, or entry any of the public lands of the United States including the District of Alaska and reserve the same for water-power sites, irrigation, classification of lands, or other public purposes to be specified in the orders of withdrawals, and such withdrawals or reservations shall remain in force until revoked by him or by an Act of Congress.'

"It was under this Act that some of the lands here involved were reserved for a power site. But the Act of June 25, 1910, by its very terms, did no more than withdraw these public lands 'from settlement, location, sale or entry'. The Act did not purport to touch or change in any way the provision of the Desert Land Act that pertains to water rights. If the words of the 1910 Act are to control, water rights remain undisturbed. The lands remained 'public lands', save only that settlers could not locate on them. I assume that the United States could have recalled its grant of jurisdiction over water rights, saving, of course, all vested rights. But the United States has not expressly done so; and we should not construe any law as achieving that result unless the purpose of Congress is clear.

"The reason is that the rule adopted by the Court profoundly affects the economy of many States, ten of whom are here in protest. In the West, the United States owns a vast amount of land, in some States, over 50 per cent of all the land. If by mere Executive action the federal lands may be reserved and all the water rights appurtenant to them returned to the United States, vast dislocations in the economies of the Western States may follow: For the right of withdrawal of public lands granted by the 1910 Act is not only for 'water-power sites' but for a host of public projects—'irrigation, classification of lands, or other public purposes.' Federal officials have long sought that authority. It has been consistently denied them. We should deny it again. Certainly the United States could not appropriate the water rights in defiance of Oregon law, if it built the dam. It should have no greater authority when it makes a grant to a private power group."

The foregoing discussion points up the need for clarification of the whole question by appropriate action of the Congress in enacting a law that will be so specific and direct that the Supreme Court can never again find loopholes to take back what the Congress and the states have considered to be the rights of the states.

The court has said that the Congress has the power to do these things but that it has not done so. This much is certain: The Congress has made its intent clear to everyone except the United States Department of Justice and the United States Supreme Court. A number of bills have been introduced in this and the preceding Congress to spell out more clearly this often expressed intent. The western states are hopeful that such legislation will be enacted during this 85th Congress so that the uncertainties in the state-federal relations concerning western waters will be finally cleared up.

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WATER—A LIMITING RESOURCE?

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(Proc. Paper 1754)

ABSTRACT

This paper emphasizes the probable degree of magnitude of the anticipated demand for water in the United States. It compares the over-all availability of water in the United States with the major domestic, agricultural, and industrial demands made upon the supply. It ventures to predict future demands in conformity with past and present trends of use. It is not designed to be comprehensive in scope, as many uses and demands are neglected. It is designed to evoke wide discussion of the implications inherent in the apparent adverse balance between supply and probable demand, and to engender recommendations for present and future action to prevent exhaustion of the supply.

INTRODUCTION

The availability and use of water is vital to the maintenance of present-day civilization. The use, and frequently the consumption, of water is necessary in the production of food and fiber, in the generation of fuel-electric energy, in the manufacture of industrial products and last, but not least, in the maintenance of the domestic environment of the individual.

This paper abruptly invites attention to the fact that the available water supplies of the United States are apparently insufficient to support a growing population, accompanied by a modest increase in the standard of living, for more than a comparatively short period into the future. It emphasizes the vital importance of immediate action to accelerate pure and applied research, and the design of the necessary facilities, directed to the accomplishment of the demineralization of sea water efficiently and economically. In the view of the writer this must be accomplished by the turn of the century. This will require that a sizeable portion of domestic, municipal, and industrial uses be supplied from such source.

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1. Sacramento, Calif.

The paper is limited to a discussion of the major uses, named in the first paragraph, of the available water supply. Other uses of importance, not discussed herein, are evaporation from water surfaces utilization of water for maintenance of stream flow, and the support of fish and wildlife, transportation, dilution of poor quality waters and effluents, and hydroelectric energy generation. These uses of the common water supply must be kept in mind, however, as they exert considerable influence on the quantity of water available for all uses.

Neither is consideration given to the re-use of water supplies or to possibilities of the repeated use of the same quantity of water. Many of the uses considered are contemporary in time and the demands are cumulative. Additionally, the majority of the uses considered occur in the valley portions of stream basins, where opportunities for regulatory storage between consecutive uses are rarely found. This is not to decry the existence of ground water storage nor the possibilities inherent for long-term regulation of water supplies through its proper use. The characteristics of ground water storage, however, are not such as to facilitate month-to-month regulatory storage.

This paper does not evaluate the effect of varying monthly flow in the streams of the country, but presumes that sufficient storage, either above or below the surface of the ground, will be provided to regulate that portion of the available supply which is determined to be usable, with consideration to all competing demands. Nor does it give consideration to the geographical availability of water in various parts of the country, since it presumes that the necessary diversion and transmission of water supplies will be accomplished to the maximum extent practicable.

An additional source of water supply which has not been considered is artificial nucleation. It is felt by the writer that this method of generating precipitation will be of principal value in the amelioration of drought in dry-farmed areas, but that because of the limited availability of natural storage sites for additional water supplies, it cannot be considered to be a firm resource. Therefore, it is believed that weather modification would be of little assistance to irrigated agriculture, or domestic and industrial uses of water. In certain limited areas, however, where spring and summer stream flow is largely supplied by melting snowpack, current applied research in snowpack augmentation gives indication of favorable results.

Water Supply

The national water supply is assumed to be the quantity of water currently available for development in the streams and rivers of the country. The quantity considered is that which remains after the evapo-transpiration requirements of nature have been satisfied from precipitation. Much of the water evaporated or transpired is used to support the growth of food and fiber crops on over 300 million acres of farmland and to maintain pasturage on almost 800 million acres devoted to the production of animal products. Large quantities are required, in addition, to provide for the growth of natural forests and the maintenance of nearly 31 million acres of water surface in the lakes and reservoirs of the country. It is, therefore, assumed that the upper limit of presently available supply is represented by the average annual runoff to the stream system. The quantity of runoff is shown in Table 1.

TABLE 1

ANNUAL RUNOFF IN THE UNITED STATES, 1921-45[2]

Basin	Area, in square miles	Average annual runoff, in acre-feet
North Atlantic slope	148,000	152,000,000
South Atlantic slope and Eastern Gulf of Mexico	284,000	235,000,000
Mississippi River	1,250,000	449,000,000
Hudson Bay	48,000	3,600,000
St. Lawrence River	130,000	101,000,000
Western Gulf of Mexico	320,000	39,800,000
Colorado River	246,000	16,700,000
Great Basin	215,000	12,500,000*
Pacific Slope in California	117,000	57,900,000
Columbia River and coastal streams in Oregon and Washington	262,000	250,000,000
TOTALS	3,020,000	1,318,000,000

* Estimated by author

The average runoff of 1,318,000,000 acre-feet, as given in Table 1, amounts to about 8.1 inches in depth on the total area. Studies by the United States Weather Bureau indicate that, for the 1921-45 period, the annual precipitation amounted to about 30 inches in depth. Thus, the indicated evapotranspiration use of water amounted to about 21.8 inches annually.

Water Use

Public water supply systems, serving areas containing populations in excess of 25,000 people, provided water supplies amounting to 13,174,000 acre-feet to 79,596,000 persons in 1953.[3] This is equivalent to about 148 gallons per day per person. Using this computed daily use, annual quantities of municipal water use, as reported by the United States Geological Survey, have been expressed in terms of the population served. Table 2 presents water-use data for 1950 and 1955. Saline water used by industry, according to U.S.G.S. data, is not included in the quantities of water given in the table.

Assuming that the rural daily per capita use, amounting to approximately 60 gallons, represents personal requirements for domestic uses, it appears that about 88 gallons per day per capita are used for public and industrial purposes in areas served by municipal systems. Public uses for parks, flushing, washing streets, etc., are believed to be a minor component of this use.

It is, therefore, assumed that 75 gallons per day per capita are used in industrial activities other than fuel-electric energy generation, resulting in the industrial use, from municipal supplies, of 7,900,000 acre-feet in 1950 and 9,700,000 acre-feet in 1955. The total industrial use of water supply, other than for power generation, is then estimated to be 29,600,000 acre-feet in 1950 and 45,500,000 acre-feet in 1955.

Water used for irrigation represented an application of 3.37 feet in depth on the irrigated area in 1950, and 3.14 feet in depth in 1955. This compares

TABLE 2

USE OF FRESH WATER IN THE UNITED STATES[4]

Class of use	1950 Quantity, in acre-feet	1950 Daily use, in gallons per capita	1950 Population served	1955 Quantity, in acre-feet	1955 Daily use, in gallons per capita	1955 Population served
Individual and incidental industrial						
Rural	4,030,000	64	56,100,000	2,800,000	56	50,300,000
Municipal	15,700,000	148	94,600,000	19,000,000	148	114,900,000
Industrial, from private sources						
Fuel-electric power generation	43,000,000			67,200,000		
Other industry	21,700,000			35,800,000		
Irrigation	88,500,000			90,700,000		
TOTALS	172,930,000		150,700,000	215,500,000		165,200,000

with the over-all national average of 1.82 feet in depth used in evapo-transpiration processes. Since the volume of crop growth (and value) is, up to a certain point, closely related to the quantity of water consumed in the growth process, it is assumed that a similar relationship could be obtained in comparing crop values from irrigated and dry-farmed areas. Table 3 presents available data bearing on this relationship.

TABLE 3

CROP VALUES IN THE UNITED STATES[3]

Year	U. S. Bureau of Reclamation Projects: Irrigated acreage	Value of crops	Value per acre	Total United States: Harvested crop acreage	Value of crops	Value per acre
1939	3,140,000	$114,100,000	$37	324,000,000	$ 5,700,000,000	$18
1944	4,164,000	$411,200,000	$99	353,000,000	$14,440,000,000	$41
1949	4,821,000	$351,700,000	$73	352,000,000	$16,300,000,000	$46
AVERAGE			$70			$35

The irrigated acreage in the entire United States (see Table 6) has increased from 6.6 per cent of the total cropped acreage in 1939, to 7.6 per cent in 1949. However, the proportion is small and it is not believed to affect greatly the general conclusion, drawn from the data in Table 3, that the irrigated acreage will produce twice the value (and volume) of the dry-farmed acreage. A comparison of the quantity of water available to promote crop growth, as given above, leads to a similar general conclusion.

Gross National Product

The gross national product (GNP) represents the total national output of goods and services at market prices. It measures this output in terms of the expenditures by which these goods are acquired. The goods and services included in GNP are, for the most part, those actually bought for final use. The GNP also measures the product attributable to the factors of production supplied by the population. The GNP is thus representative of total production and of the standard of living currently enjoyed.

The gross national product, both total and farm, is given in Table 4, together with per capita values, for the period since 1910. Values given, based on standard values in terms of 1947 dollars, are comparable between themselves. It appears that the GNP attributable to farm production has remained fairly stable since 1930. On the other hand, the nonfarm GNP, representing all other goods and services provided to the nation, has increased almost 160 per cent in the 25-year period from 1930 to 1955. This value integrates the effects of increases in the standard of living and the production of many goods and services unknown, or in the experimental stage, a quarter of a century ago.

Water is an essential factor in the manufacture of many of the products which, collectively, constitute our material standard of living. Therefore, it is believed that there should be some relationship between the use of water

TABLE 4

GROSS NATIONAL PRODUCT IN THE UNITED STATES[3]

Year	GNP, in millions of dollars*			Population, in 1,000's			GNP, in dollars per capita	
	Farm	Other	Total	Farm	Other	Total	Farm	Total
1910	15,950			32,100	59,872	91,972	173	
1920	16,790			31,820	73,890	105,710	159	
1930	17,070	132,230	149,300	30,570	92,205	122,775	139	1,216
1940	19,530	152,070	171,600	30,550	101,119	131,669	148	1,303
1950	23,130	241,570	264,700	25,015	125,682	150,697	153	1,757
1955	25,200	293,600	318,800	22,310	142,940	165,250	153	1,929

* In 1947 dollars

and the GNP attributable to other sources than agriculture. Such a relationship is shown in Table 5 for the years 1950 and 1955, for which data on industrial use of water are readily available. It appears that the per capita use of water in support of production is increasing at a very rapid rate. The per capita value of the GNP is also increasing, although at a lesser rate.

A projection of the trend of increase in the non-agricultural GNP indicates an estimated value of approximately $3,450 per capita with a population of 300,000,000, and $4,500 per capita with a population of 450,000,000, an increase of 194 per cent and 253 per cent over the 1955 per capita value, respectively. For the purpose of this paper, it is conservatively assumed that the increase in use of water to support the total product will increase approximately 50 per cent, to a value of 0.40 acre-feet per capita, with a population of 300,000,000 and will continue to increase at the same rate with future increases in population. The effect on the use of water will be discussed in a succeeding section.

TABLE 5

INDUSTRIAL FRESH WATER USE IN THE UNITED STATES

Year	Population, in 1,000's	Industrial water use: In 1,000 acre-feet: Fuel-electric	Industrial water use: In 1,000 acre-feet: Other	Industrial water use: In acre-feet per capita: Fuel-electric	Industrial water use: In acre-feet per capita: Other	Nonagricultural GNP: In $1,000,000's	Nonagricultural GNP: In dollars per capita
1950	150,697	43,000	29,600	0.285	0.196	$241,570	$1,603
1955	165,250	67,200	45,500	0.407	0.275	293,600	1,777

Agricultural Production

Water used in agriculture provides for the growth of food and fiber products for consumption and for the production of feed for livestock. Of the approximately 1,904 million acres comprising the continental United States, agricultural operations make use of about 1,158 million acres. Croplands amount to 394 million acres and pasturage and grazing occupy about 764 million acres. This general relationship has remained essentially stabilized since 1910, generally increased farm productivity having apparently compensated for increases in population. Inasmuch as the production of animal products is as essential a part of the standard of living as foods and fibers, it is believed that the available cropland will remain at essentially the present level into the indefinite future. Of the remaining lands in the United States, 555 million acres are forest and woodland areas, and 191 million acres are devoted to miscellaneous uses, or are otherwise unavailable for agricultural operations.

The harvested cropland in the United States, both dry-farmed and irrigated, for the period since 1910, is shown in Table 6. In a preceding section, it has been estimated that an irrigated acre will, on the average, produce twice the crop volume of the dry-farmed acre. On this basis, an equivalent

harvested acreage has been computed, shown in Table 6, consisting of dry-farmed acreage plus twice the irrigated acreage.

The equivalent dry-farmed acreage per capita has exhibited a consistent downward trend from 3.66 acres per capita in 1910 to 2.19 acres in 1955. At the same time the farm GNP, in terms of 1947 dollars, has increased from about $47 per acre in 1910 to about $70 per acre in 1955. Inasmuch as it has been indicated that the farm GNP per capita has apparently stabilized at about $155, it is felt that the farming industry has, at this time, essentially reached a position of agricultural and economic balance. In the immediate future, increases in population should, therefore, be accompanied by generally equivalent increases in over-all productivity. With a stabilized cropland area, this will require increases in the irrigated acreage.

Further major reduction in the acreage cropped per capita will probably occur when the GNP attributable to farm production increases in per capita value. Such increases will create conditions conducive to intensification of efforts to improve cropping practices. These efforts will be directed toward land management, soil conservation, proper use of water and fertilizers, and similar advanced practices. It is not contemplated, however, that the cropped acreage will expand at the expense of that devoted to production of animal products. The management of the latter acreage will be forced, by economic pressure, to improve productivity in a manner paralleling that of the cropped acreage. It is felt that the requirement of continually increased productivity is, in itself, a sufficient challenge without the added incubus of a reduction in available acreage.

The prediction of future trends in agricultural water utilization is based upon assumptions which, in turn, result in predictions valid only for the indicated circumstances. The assumptions made herein are:

(1) The present degree of utilization of agricultural land is 67 per cent in a scale of 100. In other words, a 50 per cent increase in present per acre volume of production can be made.
(2) The present trend of improvement in productivity of cropped acreage will continue and will result in a value of 2.0 equivalent acres per capita with a population of 200,000,000.
(3) The value of 2.0 equivalent acres per capita will be maintained until a population of 300,000,000 has been reached, after which time it will decrease to 1.4 acres, representing 100 per cent utilization, with a population of 450,000,000.
(4) Harvested cropland will expand to include the total available 394,000,000 acres at a population of 300,000,000. Other required expansion will take place through increases in irrigated acreage.
(5) Of the present (1955) irrigated acreage, 1,000,000 acres is assumed to exist in other than the principal irrigation states. It is assumed that two-thirds of the total cropland acreage will ultimately be irrigated in both present irrigation (semi-arid) and dry-farmed (humid) areas. It is further assumed that increases in irrigated lands in both areas will occur in a parallel manner.
(6) The annual applied water requirement of irrigated land in the semi-arid regions will be 3.25 acre-feet per acre. In the humid regions the supplemental requirement will be 1.25 acre-feet per acre.

Tables 6 and 7 illustrate the application of the above assumptions. It will be noted that future projections in these and succeeding tables are based upon

population. The year in which this population is attained is not shown, since it depends upon the specific projection favored by the reader.

TABLE 6

CROPPED ACREAGE IN THE UNITED STATES

Year	Population, in millions	Cropped acreage, in millions of acres: Dry-farmed	Irrigated	Total	Equivalent acreage*	Equivalent cropped acreage, per capita
1910	91.97	307.57	14.43	322.0	336.4	3.66
1920	105.71	342.81	19.19	362.0	381.2	3.61
1930	122.78	339.45	19.55	359.0	379.5	3.08
1940	131.67	299.86	21.14	321.0	342.1	2.60
1950	150.70	318.77	26.23	345.0	371.2	2.46
1955	165.25	304.10	28.90	333.0	361.9	2.19
	180.0	318.0	30.0	348.0	378.0	2.1
	200.0	326.0	37.0	363.0	400.0	2.0
	250.0	256.0	122.0	378.0	500.0	2.0
	300.0	188.0	206.0	394.0	600.0	2.0
	350.0	158.0	236.0	394.0	630.0	1.8
	400.0	148.0	246.0	394.0	640.0	1.6
	450.0	148.0	246.0	394.0	640.0	1.4+

* Dry-farmed acreage plus twice the irrigated acreage.

Industrial Use of Water

It has been shown previously that the industrial use of water has undergone a tremendous percentage increase in the period from 1950 to 1955. It is probable that the increase in the standard of living, as represented by the nonfarm GNP, from about $1,600 to about $1,775 (Table 5) per capita, has contributed to the increase in the industrial use of water.

It is assumed that the 1955 use of water, in general industrial activities, amounting to about 0.28 acre-feet per capita, will undergo an increase of about 50 per cent to 0.40 acre-feet per capita when the population has reached 300,000,000, and maintain the same rate of increase thereafter. This increase is assumed to occur in conformity with increases in the standards of living, although at a lesser rate due to the necessity for increased productivity per acre-foot of water. It is also assumed that the use of electrical energy

TABLE 7

ESTIMATED AGRICULTURAL WATER REQUIREMENTS IN THE UNITED STATES

Year	Population, in millions	Irrigated acreage, in millions of acres		Water requirements, in millions of acre-feet		
		Semi-arid region	Humid region	Semi-arid region	Humid region	Total
1950	150.7	26.23		88.5		88.5
1955	165.25	27.90	1.0	89.4	1.3	90.7
	180.0	28.5	1.5	92.6	1.9	94.5
	200.0	32.0	5.0	104.0	6.0	110.0
	250.0	79.0	43.0	257.0	54.0	311.0
	300.0	125.0	81.0	406.0	101.0	507.0
	350.0	141.0	95.0	458.0	119.0	577.0
	400.0	147.0	99.0	478.0	124.0	602.0
	450.0	147.0	99.0	478.0	124.0	602.0

Total croplands: Semi-arid region - 235,000,000 acres
Humid region - - - 159,000,000 acres

and of water used in generating steam energy will, based on projection of present trends, increase in the future to the extent shown in Table 8. The estimated general industrial increase in water use is set forth in Table 9.

Domestic and Municipal Uses of Water

In a previous section, it was estimated that the domestic use of water by individuals averaged 60 gallons per day per capita and that municipal and miscellaneous uses, except industrial, averaged 13 gallons per day per capita. It is assumed that domestic and municipal uses, due to increased use of air conditioning, new household appliances, increased use in parks and recreational areas, etc., will, in the future, increase about 67 per cent to an over-all figure of 125 gallons per day per capita with a doubled population of about 350,000,000, and remain constant thereafter. Water requirements computed in accordance with such assumptions are given in Table 10.

SUMMARY

The foregoing discussion has emphasized the probable degree of magnitude of the anticipated demand for water in the United States. Exception may readily be taken to many of the assumptions made in order to predict total requirements. However, although analyses of the various separate uses of water may be challenged, it is believed that the general indications of tremendous increases in demand over the next few decades are alarming in their implications.

TABLE 8

ESTIMATED WATER REQUIREMENTS FOR STEAM POWER GENERATION

Year	Population, in millions	Energy, in billions of kilowatt-hours	Per cent of total energy production		Kilowatt-hours per capita		Water use	
			Steam	Hydro	Total	Steam	In acre-feet per capita	In millions of acre-feet
1930	122.8	90.4	66	34	736			
1940	131.7	140.3	67	33	1,065			
1950	150.7	325.4	71	29	2,160	1,530	0.285	43
1955	165.3	546.4	79	21	3,305	2,610	0.407	67
	180.0	675.0	81	19	3,750	3,040	0.46	83
	200.0	820.0	83	17	4,100	3,400	0.50	100
	250.0	1,190.0	85	15	4,750	4,040	0.58	145
	300.0	1,550.0	87	13	5,150	4,480	0.63	189
	350.0	1,925.0	88	12	5,500	4,840	0.67	235
	400.0	2,325.0	89	11	5,800	5,160	0.71	284
	450.0	2,700.0	90	10	6,000	5,400	0.73	329

TABLE 9

ESTIMATED GENERAL INDUSTRIAL USE OF WATER

Year	Population, in millions	Water use	
		In acre-feet per capita	In millions of acre-feet
1950	150.7	0.196	29.6
1955	165.25	0.275	45.5
	180.0	0.31	55.0
	200.0	0.34	68.0
	250.0	0.37	92.0
	300.0	0.40	120.0
	350.0	0.43	151.0
	400.0	0.46	184.0
	450.0	0.49	221.0

TABLE 10

ESTIMATED DOMESTIC AND MUNITIPAL WATER REQUIREMENTS

(Industrial use of water not included)

Year	Population, in millions	Water use, in gallons per day per capita	Total water use, in millions of acre-feet
1950	150.70	70	11.8
1955	165.25	65	12.1
	180.0	77	16.0
	200.0	89	20.0
	250.0	101	28.0
	300.0	113	38.0
	350.0	125	49.0
	400.0	125	56.0
	450.0	125	63.0

The assumptions and projections made in the course of this analysis were, it is believed conservative in relation to present trends of use. Therefore, it is felt that predicted use of water, as stated herein, can be expected to occur as a result of growth in population and increased standards of living. In this connection, estimates prepared by others are of interest. Paley[5] estimated that the requirement for the use of water by 1980 would amount to 392,000,000 acre-feet annually. The equivalent estimate by the writer amounts to 368,000,000 acre-feet. Woodward[6] has estimated the water use by 1980 to amount to 669,000,000 acre-feet, with a population of about 275,000,000. His estimate agrees closely, in terms of quantity versus population, with that of the writer. The writer, however, has used the U. S. Census Bureau conservative estimate, involving return to the pre-war fertility rate by 1975, and hence does not reach that population until shortly after the year 2000.

With over 15 per cent of the available water supply presently utilized, and with the very real prospect of doubling the present population by the first decade of the next century, only about 50 years remain to establish, and to a large extent implement, the substitution of alternative sources of water for much of the existing and future demand. The regulatory storage requirements needed to make 40 to 50 per cent of the total national water supply available for use are staggering, although that quantity of water will apparently be required solely for use by irrigated agriculture before the end of the century.

The total estimated future demands on water supply in the United States are given in Table 11. The anticipated date by which such demand may be expected, based upon the most conservative of the Census Bureau estimates of population growth, is given in the last column of the table. It should be pointed out, however, that estimates of water demand which have been made in this

paper are related to population and not to time. The purpose of the time scale shown in Table 11 is solely to emphasize the immediacy of the problems presented.

Very little information is available on total investment in water service facilities. That which is most readily available(3) pertains to irrigation water supply investment during the period from 1940 to 1950. During that period, over $800,000,000 on a rapidly rising cost scale, was expended to bring irrigation water to about 5,000,000 acres previously unirrigated. On that basis, the prospective cost of providing a water supply by the year 2000 for about 160,000,000 acres not now irrigated, but required to feed a population of 275,000,000, would be about 26 billions of dollars, or 13 times the 1950 historical capital investment for all irrigation enterprises. Based on the U.S.B.R. composite price index, the cost would be about 34 billion dollars, or about $310 per unit increase in population. This does not take future increases in construction cost into account.

The foregoing cost pertains only to water supplies for irrigated agriculture. Additionally, there will be correspondingly large sums involved in providing water supplies for domestic, municipal and industrial uses. From the financial point of view, when contemplating the investment of funds in such amounts over either the next quarter, or half, century, the questions of source of funds and ability to amortize appear to be paramount. It is, therefore, felt that the immediate initiation of positive action is imperative.

A preliminary analysis suggests several courses of action which may tend to counteract or offset the adverse water supply situation presented by this analysis. The following list does not pretent to be either encyclopedic or exclusive. However, it is believed that it will serve to indicate the widespread

TABLE 11

ESTIMATED FUTURE WATER USE IN THE UNITED STATES

Year	Population, in millions	Water use, in millions of acre-feet					Per cent of total supply	Estimated year in which attained
		Irrigation	Domestic and municipal	Electric power	General industry	Total		
1950	150.7	88.5	11.8	43.0	29.6	172.9	13.1	
1955	165.25	90.7	12.1	67.0	45.5	215.3	16.3	
	180.0	94.5	16.0	83.0	55.0	248.5	18.8	1965
	200.0	110.0	20.0	100.0	68.0	298.0	22.6	1975
	250.0	311.0	28.0	145.0	92.0	576.0	43.7	1995
	300.0	507.0	38.0	189.0	120.0	854.0	64.8	2015
	350.0	577.0	49.0	235.0	151.0	1,012.0	76.8	2035
	400.0	602.0	56.0	384.0	184.0	1,126.0	85.4	2055
	450.0	602.0	63.0	329.0	221.0	1,215.0	92.2	2070

implications, and the basic nature of the approach to, national water conservation policy.

(1) Continuing and intensified public education in water conservation practices.
(2) Re-use by the steam-electric industry (after heat removal) of most of the water required for cooling generating equipment and the production of steam.
(3) Redesign of some industrial equipment so as to utilize saline or waste waters.
(4) Strict economy in the use of agricultural water and the further development of methods of accelerating food and fiber production in relation to evapo-transpiration.
(5) Reclamation, local storage, and re-use of industrial process water.
(6) Accelerated research in the processes of demineralization of saline or brackish water.
(7) Construction and operation of sea water conversion plants along the coast, and the use of demineralized sea water for all domestic and industrial purposes on all possible lands.
(8) Establishment of nuclear-electric energy generating plants near the sea coast, utilizing sea water for operation, and transmission of the output considerable distances inland, even at the sacrifice of generated power.
(9) Integration of the economies of the United States and Canada, utilizing the combined land and water resources for the best interests of all.
(10) Relocation of industry to the seacoast, reserving the interior for agriculture to the maximum extent. This, of course, requires that national defense industrial dispersion requirements be subordinated as a result of the establishment of world-wide peace, problematical in the light of existing political pressures and ideologies.

Eventually, in spite of the possible measures taken to conserve and supplement the available water supply, the burgeoning population of the world will, in the future, present the engineering profession with problems that can scarcely be imagined today. However, the present-day engineer must assume the responsibility for instituting all of the conservation measures available within the limits of our existing technology. This is the present challenge which is facing the engineering profession.

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LAND SUBSIDENCE DUE TO GROUND-WATER DEVELOPMENT

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(Proc. Paper 1774)

INTRODUCTION

In several areas in California intensive development of ground water has been accompanied by marked subsidence of the land surface. The areas of known substantial subsidence believed to have been caused chiefly by withdrawal of ground water are the Santa Clara Valley in Santa Clara County, the Los Banos-Kettleman City, Tulare-Wasco, and Arvin-Maricopa areas in the San Joaquin Valley, and the La Verne area east of Los Angeles; and in addition, a special case, the Delta area at the confluence of the Sacramento and San Joaquin Rivers. The location of these areas is shown on Figure 1. Subsidence has occurred in many other areas of ground-water development in California, but in general has not been of sufficient magnitude or of such a nature to have created noticeable problems to date. In the areas of known substantial subsidence, the subsidence has created problems, primarily related to construction and maintenance of engineering structures, but also problems in ground-water withdrawal and in land use.

This paper presents a brief description of the subsidence in the six areas, outlines the principal problems that have developed, describes what is being done at the present time to determine the causes, and suggests additional work needed as a basis for making plans to alleviate or minimize the various problems caused by land subsidence.

The subsidence of greatest vertical magnitude in California is the one at the Wilmington oil field. That subsidence is mentioned only briefly in this paper because it is caused chiefly by decline in pressure in the oil zones due to removal of oil and gas rather than ground water.

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a. Presented at the October, 1957 ASCE Convention in New York City, N. Y. Publication authorized by the Director, U. S. Geological Survey.

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FIGURE 1.

AREAS OF LAND SUBSIDENCE IN CALIFORNIA BELIEVED TO HAVE BEEN CAUSED CHIEFLY BY WITHDRAWAL OF GROUND WATER

Areas of Land Subsidence

Santa Clara Valley

The area of land-surface subsidence in the Santa Clara Valley extends from Redwood City southeast about 25 miles to and beyond San Jose and affects an area of about 200 square miles, which is also an area of intensive ground-water development. The subsidence began about 1918 and had reached 8.4 feet at bench mark P 7 in San Jose by August 1956. The average annual rate of subsidence at bench mark P 7 from 1948 to 1956 was 0.33 foot per year. The subsidence has occurred almost wholly within the area of confined water and has not been appreciable in areas of unconfined water, which are underlain chiefly by sand and gravel. Comparison of time plots of subsidence and water-level fluctuation in wells shows that the rate of sinking has corresponded in general with the rate of decline of artesian head and that subsidence virtually ceased in 1937, during a marked recovery of water level commencing in 1935, and began once more in the forties during a period of accelerated decline of head. Furthermore, water-well casings in the San Jose area are known to have protruded several feet above the land surface during the course of the subsidence, proving that compaction was occurring within the depth penetrated by the casings.(1) Thus, available evidence indicates that decline of artesian head in the confined aquifers due to intensive withdrawal of ground water is the principal cause of land subsidence in the Santa Clara Valley.

Los Banos-Kettleman City Area

The Los Banos-Kettleman City area is in the west-central part of the San Joaquin Valley, chiefly in Fresno County, and is an area of intensive ground-water development. The fresh-water-bearing deposits include an upper unit of clay, silt, and sand, 400 to 800 feet thick; a middle unit of impervious diatomaceous clay, 20 to 120 feet thick; and a lower unit of clay, silt, and sand, commonly 600 to 1,500 feet thick but locally as much as 2,500 feet thick.

The water table in the upper unit is 10 to 300 feet below the land surface and has not changed greatly from its initial position. The water in the lower unit is confined in most of the area by the diatomaceous clay. Most of the ground-water development has occurred since 1940. The heavy pumping draft from the lower unit (probably 80 percent of the current total pumpage of more than 1 million acre-feet annually in this part of the San Joaquin Valley) has drawn down the artesian head as much as 300 feet.

Subsidence of the land surface in the Los Banos-Kettleman City area, which was noted as early as 1943(2), by 1955 had reached 16 feet west of Mendota and 15 feet north of Huron, where the maximum rate of subsidence in 1955 was about 1.3 feet a year.

In general the distribution, magnitude, and rate of subsidence appear to coincide roughly with the amount and rate of decline of the artesian head of the confined water. However, subsidence of soil and near-surface material (to depths that exceed 100 feet) has occurred locally in two areas 4 to 6 miles wide and aggregating 22 miles in length along the west edge of the valley, since the first application of irrigation water to the land surface. These facts suggest that two principal causes of the land subsidence are decline of artesian head due to heavy withdrawals of ground water and near-surface compaction due to application of irrigation water. There may be others.

Tulare-Wasco area

The Tulare-Wasco area in the southeastern part of the San Joaquin Valley, in Tulare and Kern Counties, is an area of intensive ground-water development. In the western part of this area, water is confined at a depth of several hundred feet below the land surface by a diatomaceous clay that extends about a mile east of Earlimart and Delano. Other confining beds occur to the east. Water levels in the area have declined greatly since 1905. The decline in head in confined aquifers has been as much as 125 feet near Delano and 230 feet near Richgrove, chiefly since 1921.

Land subsidence in the Tulare-Wasco area was not much more than 1 foot in 1931 but by 1954 it had reached 10.2 feet at bench mark T 88, about 4 miles north of Delano.(2) A map prepared by the Bureau of Reclamation from comparison of Geological Survey topographic maps made in 1926 and 1953-54 shows a maximum subsidence of 13 feet 1 mile east of Highway 99 and 3 miles north of Delano.(3) About 450 square miles of land subsided more than 1 foot in the 6 years 1948-54.

Comparison of change in artesian head in confined aquifers and subsidence of the land surface shows fair correlation, suggesting that decline in artesian head has been a major cause of subsidence. There may be other causes, however.

Arvin-Maricopa Area

Ground-water development in the Arvin-Maricopa area has been intensive, much of it occurring in the past 10 years. Leveling control in this area is poor, but vertical displacements are known to have occurred, due in part to tectonic movements along the White Wolf fault. Whitten (4) shows that earth movements in the Arvin-Wheeler Ridge area along U.S. Highway 99 have produced subsidence of at least 1.5 feet between Bakersfield and the White Wolf fault and uplift of 2 feet or more south of the White Wolf fault. The subsidence north of the fault probably is related at least in part to ground-water withdrawal and decline in artesian head. A basic level network was established in the Arvin-Maricopa area early in 1957.

La Verne Area

Land subsidence in the La Verne area 35 miles east of Los Angeles was first noted in 1931 by Alva Smith, city engineer of La Verne. Subsidence along a 2.5-mile length of the distribution system of the Colorado River aqueduct in the La Verne area has been observed since 1933.(5,6) Maximum recorded subsidence from 1933 to 1950 was 1.8 feet. Subsidence of other bench marks between 1923 and 1931 was as much as 1 foot, so the maximum subsidence in the area must have been at least 3 feet.

Development of ground water in the La Verne area has been intensive for many years; wells are as much as 1,000 feet deep and tap confined water in part. Water levels in wells declined 100 feet or more in the twenties and early thirties. The subsidence has been attributed to decline of water level, although no detailed study has been made.

Sacramento-San Joaquin Delta

The peat lands of the delta at the confluence of the Sacramento and San Joaquin Rivers underlie at least a quarter of a million acres. Subsidence of the peat lands has been studied by Weir[7] since 1922. Drainage of the peat lands for cultivation began in 1850, but at least one of the islands was not reclaimed until 1921 (Mildred Island). The peat ranges in thickness from a featheredge to more than 40 feet locally, but in the central area is between 20 and 40 feet thick.[8]

Weir assumes that the delta islands were at mean sea level prior to reclamation. The land surface of most of the islands south of Isleton and north of Stockton was more than 10 feet below sea level in 1953,[9] but the topographic maps of the Geological Survey based on field surveys of 1952 show that only in an area of about 1 square mile in the eastern part of Sherman Island was the land surface more than 15 feet below sea level. This suggests that the average subsidence from the time drainage began to 1952 was 11 to 14 feet.

Leveling by Weir shows that subsidence on Mildred Island was 9.29 feet from 1922 to 1955, at a reasonably uniform rate averaging 0.28 foot per year. Why subsidence of islands that were reclaimed prior to 1900 is not almost twice as great is not known.

Weir concluded that the causes of subsidence were as follows: Oxidation (believed to be the major cause), compaction by tillage machinery, shrinkage by drying, burning, and wind erosion.

In an intensive study of the subsidence of peat beds in the Florida Everglades, Stephens and Johnson[10] concluded that the principal cause is the slow oxidation due to action of aerobic bacteria above the water table, and hence that the rate of subsidence can be kept at a minimum by maintaining the water table at the maximum elevation permissible for crop growth. Doubtless the oxidation of the delta peats is from the same cause. Hence, the primary cause of subsidence in the delta is the withdrawal of ground water by drains constructed to lower the water table.

Problems Caused by the Subsidences

The principal problems caused by the subsidences described briefly in this paper can be divided into problems related to (1) engineering structures, including maintenance or repair of presently existing structures, and planning, construction, and maintenance of proposed structures; (2) continued groundwater withdrawal or expanded development, and (3) land use. They are described briefly in following paragraphs, in part summarized from a report by the Inter-Agency Committee on Land Subsidence in the San Joaquin Valley.[3]

Problems Related to Engineering Structures

Of irrigated areas where subsidence has occurred, several are traversed by costly existing canals or conduits of large capacity and low gradient, and additional trunkline canals and distribution systems are proposed. The Bureau of Reclamation has spent approximately $100,000,000 in construction of the 270 miles of the Delta-Mendota and Friant-Kern Canals in the San Joaquin Valley. Sections of both these canals traverse areas of subsidence. Neither

canal is operated at design capacity in the areas of subsidence at the present time, so that the effects are not as serious yet as they might have been, and extensive repairs have become necessary only along about 10 miles of the Delta-Mendota Canal. The land along this reach of canal subsided as much as 3.5 feet between 1946 and 1955, and plans are being made for substantial repairs. Should subsidence continue for many years, problems and costs involved in remedial measures would increase rapidly.

The California Department of Water Resources estimates the cost of the proposed Feather River Canal, traversing the west side of the San Joaquin Valley from the delta area to the Tehachapi Mountains, at about $200,000,000. This canal would pass through areas of pronounced subsidence for at least a quarter of its length. Provisions for land-surface subsidence will increase the cost of construction in these areas substantially.

The proposed San Luis Canal of the Bureau of Reclamation is estimated to cost $70,000,000. An allowance of $1,500,000 has been made for increased earthwork required on the San Luis Canal to allow for subsidence.

The Metropolitan Water District of southern California has encountered problems related to land-surface subsidence along the Colorado River aqueduct and its distribution system.

In all these large trunkline canals or conduits, planning for remedial measures or for new construction is made very difficult because of lack of knowledge concerning location and magnitude of future subsidence. The gradient of these proposed major canals is about 0.3 foot per mile. Thus, reasonably accurate estimates of the amount of future change in elevation of the land surface are of paramount importance in planning construction and maintenance of such major structures.

In addition to the problems created by land subsidence in construction and maintenance of large main canals, subsidence has created and will continue to create problems in design, construction, and maintenance of water-distribution systems. For example, in the proposed San Luis service area of the Bureau of Reclamation within the Los Banos-Kettleman City subsidence area, distribution systems utilizing buried concrete pipe and estimated to cost approximately $130,000,000 have been proposed. If the subsidence continues at its present rates it could cause leaks and, ultimately, breaks in the pipes which, in addition to maintenance and repair costs, could cause crop losses as a result of inability to deliver water at critical times.

Land subsidence creates serious problems in many other types of engineering structures, such as drainage and sewage systems, flood-control channels and levees, roads and bridges, power installations, pipelines, and buildings, and in the surveying and mapping programs needed in the planning of these structures.

For example, in the Santa Clara Valley, levees around the southern part of San Francisco Bay have had to be constructed and raised in an attempt to keep Bay water from inundating the land and flooding highways and buildings in an area of rapid industrial development and these levees themselves create flood-control problems. In that same area, the flattening of stream grades due to the bowl-shaped subsidence and the consequent partial filling of the channels with sediment are decreasing the flood-carrying capacity of the channels and of bridge structures. Such problems are being considered in designing future highways as well as flood-control systems.

Subsidence in the lower Kings River area may considerably reduce the hydraulic capacity or stability of flood channels in that area and may

materially affect the operation of the Pine Flat Reservoir and of existing water-control structures along the lower Kings River. Subsidence along the San Joaquin River and in the Sacramento-San Joaquin Delta may affect materially several other flood-control and navigation projects of the Corps of Engineers that are either in operation or in the planning stage.

Problems that have developed to date in power installations, pipelines, and buildings have been related chiefly to compaction of soils and near-surface materials after the application of water in certain areas of low rainfall. This type of subsidence is usually accompanied by large differentials in settlement over small areas. For example, subsidence of this type in the Los Banos-Kettleman City area has damaged transmission lines of the Pacific Gas and Electric Co. Work tentatively estimated to cost $200,000 is contemplated for repair of towers on three transmission lines. Also, subsidence in this area has affected the Stanpac gas main for a distance of about 20 miles north of Panoche Junction, and pipelines of the Standard Oil Co. and Shell Oil Co. in the same area also have required repairs.

Subsidence of this type is understood to have caused damages of the magnitude of several hundred thousand dollars to military installations in the western United States during and since World War II. For example, at Gardner Air Field in the Arvin-Maricopa area, the Corps of Engineers spent many thousands of dollars to restore and protect utilities and buildings from subsidence amounting to several feet. The contrary problem caused by clay that expands when wetted has caused serious problems in maintenance of the Friant-Kern Canal.

Surveying and mapping costs have been increased greatly by problems of land subsidence. The Federal construction agencies, the State Department of Public Works, the State Division of Highways, other State planning and construction agencies, counties, municipalities, irrigation districts, pipeline companies, and many other construction agencies, both public and private, depend on accurate local vertical control. The cost of the basic vertical control of the U. S. Coast and Geodetic Survey, of the leveling and mapping programs of other Federal agencies, of State, County, and municipal agencies, and of other public and private agencies is increased substantially in areas of land-surface subsidence.

The land subsidence that has caused the greatest damage to date in repair and maintenance of drainage and sewage systems, roads and bridges, flood-control systems, power installations, pipelines, dock facilities, buildings, and oil wells is the subsidence in the harbor area of Los Angeles and Long Beach. That subsidence is not discussed in this paper because it has resulted chiefly from the decline in pressure in the oil zones due to the development of the Wilmington oil field. Cost of accomplished and planned remedial measures necessitated by the subsidence in that area is about $100,000,000.

Problems Related to Continued Ground-Water Withdrawal or Development

Deformation and failure of water-well casings and the resulting loss of wells are a common occurrence in the Los Banos-Kettleman City area and represent a large financial cost to the owners. According to a local committee established to study the problem, 258 wells failed during the period up to 1950. Wells generally fail within 10 years after completion, and many

have failed after only 1 or 2 years of operation. There are about 1,000 irrigation wells in the area at present, and their average depth is about 1,500 feet. Replacement of 100 wells each year would cost at least $1,500,000 per year. Although corrosion is probably an important factor in the well failures, the deformation and rupture of casings is testimony that land subsidence resulting from compaction of the water-bearing and associated beds is a principal cause. Full knowledge of the depths at which the compaction of sediments is occurring might lead to redesign of wells and substantial lengthening of well life.

Collapse of well casings has occurred also in the Tulare-Wasco, Arvin-Maricopa, and La Verne areas.

Land subsidence has caused protrusion of well casings as much as 3 feet above the land surface in the Santa Clara Valley, and protrusion of well casings to a lesser extent has been noted in the Los Banos-Kettleman City, Tulare-Wasco, and La Verne areas. In the Santa Clara Valley, at least, this protrusion has raised pumping equipment and has required removal of equipment and cutting off of casings.

The California Water Plan calls for extensive use of ground-water reservoirs for cyclic storage in future years. Such cyclic storage probably would cause periodic rise and decline of water levels of 100 feet or more in the ground-water basins so utilized. Although water would be introduced chiefly in areas of unconfined water, the artesian head in hydraulically connected confined aquifers also would fluctuate substantially. It is possible that in some areas such fluctuations induced by cyclic storage and withdrawal would cause subsidence during periods of decline of artesian head and might cause a lesser recovery of the land surface during periods of storage and rise in head. This problem should be investigated prior to any extensive practice of cyclic-storage operations.

Additional problems to be considered are the effect of subsidence on ground-water storage capacity and on safe yield of ground-water basins. Subsidence caused by compaction of the water-bearing system causes reduction of pore space both in the aquifers and in the finer grained associated deposits. Reduction of pore space in the Santa Clara Valley due to subsidence has been estimated as on the order of 230,000 acre-feet for the period 1919-37.(1) The volume of land subsidence in the northern part of the Los Banos-Kettleman City area (north of T. 17 S. to the Merced County line) from 1943 to 1953 has been estimated as on the order of 1,000,000 acre-feet; pumpage of ground water in that same 10-year period was about 2,000,000 acre-feet. Most of the million acre-feet of subsidence presumably was accomplished by reduction of pore space in aquifers in the lower water-bearing zone and in associated fine-grained deposits. Water yielded as a result of compaction is available only once (neglecting possible later expansion) and thus should be considered in evaluating safe yield, as it was in the study by the State Division of Water Resources in the Santa Clara Valley.(11)

Land-Use Problems

The subsidence of regional extent caused by decrease in artesian head ordinarily does not cause serious problems in land use. However, the compaction of soils and near-surface deposits caused by applying water to certain lands in the Los Banos-Kettleman City and Arvin-Maricopa areas and

probably elsewhere creates problems in land leveling and maintenance of irrigation facilities. Such problems have led locally to the use of sprinkler irrigation, sometimes after substantial financial expenditures had been made in land leveling and in repair of irrigation systems.

Solution of the Problems

Detailed knowledge concerning the extent, magnitude, rates, and causes of land-surface subsidence is essential to proper planning for repair and maintenance of structures already affected and for construction and maintenance of structures to be built in the future, as well as for continued ground-water withdrawal and development and for most economical land use. This detailed knowledge can be obtained only by adequate investigation of the areas in which subsidence has occurred to date, by determining the causes, by considering methods for alleviating or minimizing the problems caused by subsidence, and by adequate appraisal of other parts of the State to ascertain what additional areas may be susceptible to land subsidence in the future.

Such investigations should be directed toward the following specific objectives, as outlined by the Inter-Agency Committee on Land Subsidence in the San Joaquin Valley:(3)

1. To establish and maintain vertical control information on the land surface adequate to satisfy engineering and mapping needs and needs of the investigational program, and to measure the extent, rate, and magnitude of subsidence.
2. To determine causes of the subsidence and the relative magnitude attributable to different causes; also, the depth ranges within which subsidence is occurring.
3. To estimate the rates and amounts of subsidence that would occur in the future under assumed conditions.
4. To determine if any part of the subsidence is reversible and, if so, to estimate the rate and amount of possible recovery.
5. To suggest any methods that might be used to decrease or to alleviate subsidence, or to forestall some of the more serious damages resulting from subsidence.

Investigations now being made

The subsidences in the San Joaquin Valley have created such serious problems in connection with water-transportation and -distribution systems that early in 1955 an Inter-Agency Committee of interested Federal, State, university, and local agencies was formed for the purpose of formulating and carrying out a program of investigation in the San Joaquin Valley with the objectives cited above. The proposed program was outlined in a duplicated report.(3) The estimated cost of the program for investigating subsidence in the Los Banos-Kettleman City and Tulare-Wasco areas as outlined for a 3-year period of investigation is about $460,000 to supply general engineering and mapping needs, and about $500,000 for work related almost wholly to subsidence investigation needs. Intensive investigation in some phases of the work for the Los Banos-Kettleman City area was begun in 1955 and in all phases in 1956. A report covering the subsidence in the Los Banos-Kettleman City area is scheduled for completion in 1960, and considerable study of the other two areas in the San Joaquin Valley also will be accomplished by that

time. Progress reports on certain phases of the work are scheduled at an earlier date.

The land subsidence in the Santa Clara Valley is being investigated by the U.S. Coast and Geodetic Survey and the Geological Survey, working in cooperation. A level network to determine the extent and magnitude of settlement in the San Jose area was laid out in 1933, and it has been releveled 10 times, the latest in 1954. The Coast and Geodetic Survey recently published a tabulation of bench-mark elevations for the levelings through 1954. The Geological Survey is preparing a progress report at the present time which will include maps and profiles of subsidence and plots of subsidence at individual bench marks compared to fluctuation in artesian head.

The land subsidence in the La Verne area is known chiefly from repeated leveling by the Metropolitan Water District along an aqueduct feeder line. So far as known to the writer, no level network to define the extent and magnitude of that subsidence has yet been established.

In the Sacramento-San Joaquin Delta, some additional information has been obtained to supplement the local study by Weir.(7) The State has made borings to determine the thickness of the peat beds and the nature of the underlying deposits.(8) Vertical control in the Delta area was expanded in the summer of 1957.

Additional Work Needed

The program of the Inter-Agency Committee on Land Subsidence in the San Joaquin Valley should receive the support and assistance of all agencies, public and private, that are interested in or affected by the problems of land subsidence there. The activities of all agencies should be integrated and coordinated so that maximum effort can be directed toward the completion of this program and the solution of this problem for the San Joaquin Valley.

Findings of the investigations in the San Joaquin Valley should be of great assistance in the solution of subsidence problems elsewhere, but physical conditions in other areas of subsidence may be different in several aspects from conditions in the San Joaquin Valley. Therefore, all areas in California in which appreciable subsidence has occurred or develops in the future should be studied to determine the causes and to seek the best remedial measures. The first necessity of such a study, and a fundamental requirement for general engineering needs as well, is the establishment and maintenance of adequate vertical control. The adequacy of the vertical-control net of the Coast and Geodetic Survey in California should be appraised, not only with respect to areas of known subsidence but also for potential subsidence.

Second, for each area of land subsidence, bench-mark elevations obtained to date by the Coast and Geodetic Survey and by other agencies (from level lines run with adequate control, both in accuracy of leveling and in ties to stable land) should be correlated and tabulated in chronologic order in one series so that reliable and consistent records of elevation and change in elevation will be available in one publication.

Third, adequate programs of water-level measurement and of inventory of ground-water draft should be established. These will require sufficient study of the geology and hydrology to insure that the measurements will furnish adequate data on fluctuations of artesian pressure in confined aquifers as well as of the water table.

Fourth, bench marks should be established at selected depth intervals in wells so as to span the water-bearing section tapped by wells, for the purpose of determining whether or not compaction of the geologic section is occurring, and if so, how much and at what depth intervals.

Only after these basic controls are established and records collected for at least 1 to 2 years can the remainder of the investigation be made with efficiency and economy.

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THE ENGINEER AND WORLDWIDE CONSERVATION OF SOIL AND WATER

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SYNOPSIS

The role of the engineer in worldwide soil and water conservation necessary to meet increasing food requirements is emphasized.

A brief review of progress by construction of drainage systems and irrigation projects is presented. Some of the large surface reservoirs are listed, the volumes of surface-reservoir water stored for irrigation are reported; and the needs for more use of groundwater reservoirs is suggested. The necessities for efficient conveyance of water in world canals of more than a million miles in length are stressed. The relationships of efficient application of water on the farms, in the estimated 15 million irrigations per year, to worldwide soil and water conservation are outlined.

INTRODUCTION

In preparing this paper, the author had in mind four major objectives:

1. To emphasize the fact that soil and water conservation is positively essential to world progress, prosperity, and peace.
2. To clarify the fact that great progress has been made toward soil and water conservation in the construction of large dams, reservoirs, diversion structures, canals, and pumping plants for lifting surface and ground waters.

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3. To show that greater attention of the engineer to the prevention of soil water logging, salinity and alkali, by improving and lining canals and reservoirs to reduce seepage losses is very important to progress.

4. To stress the fact that in the many arid-region countries of the world, more attention to adequate land drainage, and to efficiencies in the application of irrigation water is very essential, that in arid regions irrigation and drainage are inseparable, and that both need the joint attention of the engineer to provide and perpetuate the soil and water conservation that are basically essential to world progress.

The 27 hundred million people in the world of today have many urgent needs, the first in importance being adequate supplies of food which can be produced only by efficient soil and water conservation in all countries.

In addition to its use for food production, water is essential to our worldwide welfare in many ways. Soil and water conservation are, therefore, vital necessities for the millions who live today and will be even more essential for a greater number of people of the days ahead.

The importance of water conservation and irrigation to all people is well stated by Gulhati[6] as follows:*

> Irrigation in many countries is an old art—as old as civilization—but for the whole world it is a modern science—the science of survival.

Soil conservation has many aspects. C. J. Francis,[3] Director of Engineering for the U.S. Soil Conservation Service, recently stated that:

> Soil conservation has come to mean proper land use, protecting land against all forms of soil deterioration, rebuilding eroded and depleted soil, improving grasslands, woodlands, and wildlife lands, conserving water for farm and ranch use, proper control and use of water to provide for drainage, irrigation and flood prevention, building up soil fertility and increasing yields, and farm and ranch income.

A major element of soil conservation is the control of soil erosion. Authorities estimate that soil erosion in the U.S.A. has prevented further cultivation of about 100 million acres and seriously affected crop and grazing land of nearly 300 million acres.

Also, soil erosion has moderately affected nearly 800 million acres. The author emphasizes the needs for and the activities in control of soil erosion as an important phase of worldwide soil conservation, even though in this article, major attention is given only to essential advances in arid-region land drainage and irrigation efficiencies and requirements for soil and water conservation.

Successful soil and water conservation is intimately related to conservation of all resources. The principles and practices that must be applied to conservation of natural resources in a democracy are outlined by Allen.[1] These apply as well to soil and water conservation in many lands.

Recognition by world leaders of the importance of soil and water conservation work is exemplified by the statement of President Eisenhower, made shortly after his election:

*Numerals refer to author references, capital letters to agency references.

We need to give increased attention to the improvement and reclamation of land in its broadest aspects, including, soil productivity, irrigation, drainage, and the replenishing of ground water reserve if we are adequately to feed and clothe our people to continue to improve our standard of living.

Conserving and improving our land and water resources is high-priority business for all of us.

More food from worldwide soil and water conservation will assure millions of people greater happiness, contentment, freedom, and progress.

The Civil Engineer has, for decades, been deeply interested in world welfare. His interests have been demonstrated in a large number of countries. The American Society of Civil Engineers is very much interested in world progress and welfare, and it recognizes fully that the engineer has great responsibilities in many phases of world advancement and particularly in soil and water conservation. Our Society has a great number of members in countries outside the U.S.A. Although its membership (nearly 50,000) is largely in North America, it has 65 members in Mexico, more than 1,000 members in South America, and more than 1,100 members in Europe and Asia. The Society thus is in a powerful position to contribute greatly to worldwide efforts of soil and water conservation by dissemination of information and by assisting in worldwide co-ordination of effort.

The engineer recognizes the important fact that worldwide conservation of soil and water requires the understanding and cooperative efforts and teamwork of men working in legislatures, public administrative offices, the courts and judicial agencies, industrial activities, and on the farms. The conservation task is a monumental one. Cooperative efforts toward conservation of soil and water by lawyers, judges, economists, agronomists, agriculturists, and all others interested in worldwide welfare and progress as well as engineers, is of vital importance. This cooperative effort was emphasized recently by Banks(2) who outlined four aspects of teamwork necessary in soil and water conservation:

1. Teamwork in the uses of water;
2. Teamwork among the many agencies who plan, construct, and operate water development projects;
3. Teamwork among the professional and scientific fields in adding to the store of knowledge concerning the nature, occurrence, control and utilization of water; and finally,
4. Teamwork between the professional and technical people who deal with water on the one hand and the general public on the other hand, in solving these problems.

The engineering problems involved in soil and water conservation as stated by Frevert, Schwab, Edminster, and Barnes,(4) may be divided into the five following phases: erosion control, drainage, irrigation, flood control, and land clearing. In this paper the author has concentrated attention on only two of the five phases; that is, drainage and irrigation. The activities of the engineer in land drainage in both humid and arid-climate countries and in irrigation in arid climates are important aspects of his role in soil and water conservation. Europe, Asia, and U.S.A. have made great progress since the engineer began active work in land drainage. There are millions of acres of drained land in the world today. In the U.S.A. the engineer has planned

drainage facilities and directed the construction of drains for more than 100 million acres. The facilities, the progress, and the problems in soil and water conservation by means of drainage and irrigation are the concern of the engineer in all countries.

Land Drainage for Soil Conservation

Land Drainage Needs Widely Recognized

Land drainage is recognized as important in many countries of Europe. England, Wales, Italy, Greece, and Turkey along with other countries have made real progress in the drainage of farm soils. Almost 4-1/2 million acres, or 1/7 of the cultivated land area, in England and Wales are dependent on drainage.

The Netherlands have made extraordinary progress in developing land drainage facilities. The country has drained some land that was above the level of the sea, and also provided drainage and reclamation facilities for large areas of land that were previously submerged with salty sea water. While drainage has been practiced extensively to reclaim lands in humid regions, during the past century, many thousands of acres of irrigated lands in India, Pakistan, Iran, Iraq, and neighboring countries have become water logged and nonproductive because of lack of adequate drainage. The engineer recognizes the urgent need for drainage and is, therefore, making plans for the drainage of large areas of arid-region lands in many countries with the assistance of the International Cooperative Administration (ICA) and others interested in promoting the advancement of human welfare throughout the world.

Arid-Region Land Drainage Objectives

Some of the major objectives of land drainage in arid regions are to:

1. Keep the water table depth under complete control and deep enough to prevent upward flow and evaporation of soil water with resulting concentration of soluble salts in the root-zone soils.
2. Maintain downward flow of water in saline and alkali soils.
3. Prevent the accumulation of excess soluble salts in the soil root zone and on the surface of irrigated lands.
4. Obtain general and worldwide recognition of the fact that land drainage is essential to the permanence of arid-region agriculture, and that the many benefits of drainage are greatly exceeding the costs.

Drainage Procedures to Obtain the Objectives

Some of the procedures and practices that are essential to attain the drainage objectives are:

1. Reduce, wherever possible, the salt content of irrigation water.
2. Increase the permeability of soils in which the resistance to water flow is high and extend the practices of measuring the flow of water in soils.
3. Design and construct drainage systems that are especially adapted to the physical conditions of each area that needs drainage.

4. Design and locate drainage pumping plants to get maximum water yield per foot of drawdown.

5. Improve irrigation methods, measure irrigation water, and increase irrigation efficiencies.

Progress and Cooperation in Drainage

The engineer has contributed greatly to educational progress in land drainage. He recognizes, however, the urgency of the need for adequate cooperation in land drainage with the agronomist, the economist, the chemist, and the soil physicist—all of whom have contributed to the solution of drainage problems.

The fact that the engineer in many countries is deeply concerned with the educational progress in land drainage was demonstrated by the work of Dorothy W. Graff, Librarian for the U.S.D.A., Bureau of Agricultural Engineering, in assembling during 1936 a list of about 2,000 references to drainage publications written by 1,160 authors from 45 countries.

A recent and very important contribution to the literature on land drainage is the book entitled: "Drainage of Agricultural Lands," prepared by 17 contributors, edited by James N. Luthin, and published by the American Society of Agronomy. This book contains 733 references on Land Drainage.

The development of modern machinery for the digging of trenches and placing tile drains has contributed greatly to progress of land drainage in U.S.A.(17) Power excavating equipment is now recognized to be of real value to drainage progress. The trenchers and also the dragline excavators, back hoes, and similar machines now very much used in the U.S.A. and Europe, are greatly needed for drainage progress in the Mid-East countries.

The Imperial Irrigation District of California has constructed 557 miles of main drainage channels from 7 to 10 feet in depth with modern power excavating equipment.

Shallow open drains constructed by hand labor, like the drain shown in Fig. 1, are usually inadequate and construction of deep open drains by hand labor is rather expensive.

Continued progress in drainage and land reclamation and soil and water conservation will depend on worldwide use of modern machinery and methods. The author believes fully that man can develop a permanent irrigation agriculture as recently stated by Maierhofer(11): "The engineer must develop and clarify methods of drainage and reclamation to make irrigation agriculture permanent."

Benefits from Drainage

Economic Benefits of Good Drainage Systems

Good drainage systems provide economic benefits by:

1. Increasing the productive land areas on the farm without extending its boundaries by bringing under cultivation pond areas and marshy spots, the beds of which usually have great agricultural potential.

2. Improving the quality and increasing the yield of crops.

3. Providing greater uniformity of fields, thus making the farm more easily worked by removing the mud holes and wet spots.

Figure 1. Open Drain in Iran Constructed Largely by Hand Labor

4. Preserving fertilizers.
5. Reducing floods and consequent loss of crops.
6. Decreasing the danger of drought by:
   a. Reducing evaporation from the soil surfaces and improving the soil structure.
   b. Providing larger volumes of available soil water for the plant roots by developing deeper root-zone soils.
7. Improving the chemical condition of the soil by:
   a. Removing excess alkalies and acids.
   b. Aiding nitrification and decay of organic matter.

Social and Community Benefits of Drainage

Drainage systems provide social and community benefits by:

1. Improving sanitary conditions, thus making rural life more pleasant by the removal of stagnant swamps and by the provision of outlets for wastes.
2. Making the appearance of the farm better with the results of increasing the market value, and of stimulating the pride and interest of the farmer in his work.
3. Facilitating the construction and maintenance of good and permanent rural highways, which bring many benefits.
4. Providing insect control; improving the health of the people; and improving health conditions for cattle, horses, sheep, and poultry.

Improved Health—A Major Benefit

The World Health Organization (WHO) has made important contributions toward progress in soil and water conservation by the encouragement of adequate drainage to improve health conditions. It has also encouraged the engineer to design irrigation systems, canals, waterways, flumes and pipes to convey water efficiently and to avoid ponding which permits growth of snails, mosquitos, and other "natural" enemies. Successful world progress in both drainage and irrigation is being greatly assisted by WHO.

Mickey,(12) states the primary fact is that soil under man's feet is the source of his physical being and thus soil conservation is nothing more nor less than conservation of human life, wherever it is lived, in the city as well as in the country.

Arid-Region Drainage Essentials

The engineer and the owners and operators of irrigated farms in arid-region countries, and all farm advisors should know what they can and must do in irrigation and drainage to perpetuate soil and water conservation. One-hundred years of experience in irrigation in the Western States of the U.S.A., and the widespread waterlogging of irrigated lands throughout the world due to lack of adequate drainage are ample bases for the conclusions that:

1. Irrigation and drainage cannot be divorced - in arid regions they must be considered as inseparable. The recognition and application of this basic truth is essential to the continued productivity of the irrigated lands of the world.
2. Careless and inefficient irrigation of lands is extremely expensive to the irrigators, and to the owners of lower lands and drainage systems and must be prevented.
3. Drainage alone is not enough to reclaim and make productive waterlogged, saline, and alkali lands - improved irrigation practices and modern soil management methods are indispensable and must be developed.
4. Adequate maintenance of drains must be recognized as being of great importance.

5. Drainage, like irrigation, is of vital public importance and must be recognized as indispensible in arid regions. All of the people are influenced by the improved health and better highways, and by the soil and water conservation that result from adequate land drainage.

Irrigation and Water Conservation

Centuries have passed since irrigation was first developed by the farmer, but during recent decades the engineer has made great contributions to the development of modern irrigation projects in the world. Irrigation water is now provided each year for more than 300 million acres. The design and construction of large dams, reservoirs, diversion weirs, canals, spillways, silt-control works, and related facilities constitute the major role of the engineer toward progress in the use of water resources.

In the U.S.A., irrigation water is provided for more than 30 million acres, or about 3/5 of the potential irrigated area of 50 million acres.

Water Storage Facilities

Very substantial world progress has been made toward water conservation by the use of water storage facilities.(7) These include both surface reservoirs for irrigation and flood control and ground water reservoirs from which water is obtained by artesian flow or pumping.

Surface Reservoirs

The 400-year old reservoir in Northeastern Iran, shown in Fig. 2, illustrates the pioneer storage works of the Mid East.

In 1950, twenty states of the U.S.A. had nearly 7,000 surface reservoirs each of which had a capacity of 5,000 acre-feet or more, and a total usable water storage capacity of more than 100 million acre-feet and surface area of more than 11 million acres.

It is estimated that the world has more than 25,000 surface reservoirs largely for irrigation purposes. Some have capacities of only a few thousand acre-feet whereas others have capacities of millions of acre-feet. The capacity of Lake Mead in U.S.A. is nearly 30 million acre-feet and that of Wainganga in India is more than 33 million acre-feet. The 11 reservoirs listed in Table 1 have a combined capacity of more than 200 million acre-feet, enough to cover the world's irrigated lands to a depth of more than 6 inches.

The U.S. Bureau of Reclamation surface reservoirs constructed in the past half century store more than 66 million acre feet of water. Additional reservoirs, having a total capacity of about 34 million acre-feet, have been authorized for construction in the Upper Colorado River Storage Project. The Bureau of Reclamation will, therefore, have surface reservoir water storage capacity of 100 million acre-feet when the Colorado River dams and storage facilities are completed.

The building of these large reservoirs requires the very careful attention of the engineer. As shown in Table 2, a volume of more than 130 million cubic yards of materials was used in the construction of Fort Peck Dam. Six other large dams listed in Table 2 required material ranging from 23 million to 79 million cubic yards for each dam.

Figure 2. Iran Reservoir 400 years old.

TABLE 1 - WORLD'S GREATEST RESERVOIRS

	Capacity Acre-Feet
Wainganga, India	33,300,000
Lake Mead, Hoover	31,047,000
Glen Canyon	28,040,000
Oahe	23,600,000
Garrison	23,000,000
Fort Peck	19,400,000
Pine Portage, Canada	11,136,000
Roosevelt Lake, Grand Coulee	9,402,000
Lac Casse, Canada	8,800,000
Bhakra, India	7,400,000
Hirakud, India	6,750,000
TOTAL	201,875,000

TABLE 2 - WORLD'S LARGEST DAMS

	Cubic Yards	Year
Fort Peck	130,421,000	1940
Oahe	79,070,000	*
Garrison	67,500,000	1954
Fort Randall	27,000,000	*
Hirakud, India	27,000,000	1956
Kingsley	26,000,000	1941
Gatun, Canal Zone	23,000,000	1912
Denison	18,762,000	1945
Sardis	16,976,000	1940
Cherry Creek	14,650,000	1950

* Under Construction

In early years, the engineer started the development of water storage facilities by building low nonconspicuous dams. Now many of the dams are more than 550 feet in height, as indicated in Table 3 which lists 11 selected dams ranging in height from 550 feet to 780 feet. It is important to note that many of these dams and reservoirs are constructed not only to conserve water for irrigation, municipal and industrial water uses, but also to control floods and to develop hydro-electric power. Many of these are multi-purpose projects, but water conservation is a dominant factor in the construction of most of the big dams and reservoirs.

TABLE 3 - WORLD'S HIGHEST DAMS

	Height - Feet	Years Completed
Mauvoisin, Switzerland	780	*
Hoover	726	1936
Glen Canyon	700	*
Bhakra, India	680	*
Shasta	602	1945
Kurobe No. 4, Japan	590	1956
Tignes, France	590	1953
Grande Dixence, Switzerland	580**	*
Hungary Horse	564	1953
Grand Coulee	550	1942
Bekhme, Iraq	550	*

* Under construction.

** First stage of construction; full height of dam to be 921 feet.

Ground Water Reservoirs

Centuries have passed since pioneer irrigators developed ground water by the construction of long underground tunnels known as ghanats. In some of the Eastern countries, ghanats are now very much used to obtain water. In parts of Iran, ghanats, like the one shown in Fig. 3, provide drainage for the higher lands and irrigation water for the lower lands.

Figure 3. Ghanat Outlet, Iran

Through the help of the engineer, arid-region countries have made substantial progress in the development and use of ground water for irrigation. In five western states of the U.S.A. there are 54,000 pumped wells which have a combined capacity of 75,000 C.F.S. During recent years, more than 10 million acre-feet of water from ground water reservoirs have been pumped and used annually in California where the total irrigated area is more than 7 million acres. The major use is in the Central Valley and South Coastal area which together use more than 90 percent of the volume of ground water used in California.

Texas now irrigates nearly 5 million acres, and pumps each year about 4 million acre-feet of ground water for irrigation of about 2.5 million acres with more than 1,800 pumped wells.

Arizona farmers, in 1953, pumped about 5 million acre-feet of ground water for irrigation and irrigated nearly 1.2 million acres.

These few examples illustrate the importance of ground water reservoirs in Western U.S.A. from which millions of acre-feet of water are being pumped for irrigation.

The volume of water pumped from some ground water reservoirs during recent years is much greater than the natural recharge volume. Artificial

recharge and control of the volumes of water pumped require the serious attention of the engineer to perpetuate the use of these reservoirs.

Complete Water Control

The design and construction and maintenance of dams and of reservoirs to store, control, and conserve surface water for irrigation is very important to world progress, but not sufficient.

Many other water-control activities of the engineer are very essential to permanent progress in irrigation and drainage. Two of these activities, namely, conveying the water to the irrigated lands without excessive seepage losses and irrigating the soils efficiently, are of special importance and they are considered herein.

Complete development of an irrigation project includes the provision of facilities to convey water from rivers, lakes, and reservoirs to the irrigated lands. It also includes preparation for economical and efficient application of irrigation water to the root-zone soils of the irrigation projects.

Water Conveyance Facilities and Problems

The world's needs for irrigation canals are great and varied. Many canals convey small streams of 5 to 10 C.F.S. only short distances from the water source to the land. Other canals convey streams of several thousands C.F.S. hundreds of miles from the rivers to the farms.

The Upper Ganga Canal in Uttar Pradesh, Indian, (C) has a capacity of 10,500 C.F.S. and is more than 400 miles in length.

The Lower Chenab Canal in West Pakistan, one of the largest in the world, provides water for 2.8 million acres. Its flow capacity if 11,000 C.F.S. and it has 450 miles of main canals and 2,500 miles of distributaries.

Total Length of World Canals

For estimating purposes, it is assumed that the total length of irrigation canals in the world is proportional to the area of land irrigated. The world irrigated area is approximately 10 times the area irrigated in U.S.A., and hence, the estimated total length of canals is about 1,350,000 miles. If only 3/4 of the canals need lining and other improved facilities for efficient water conveyance, the engineer should provide lining for irrigation canals of more than a million miles in length to contribute to worldwide soil and water conservation. The task is a monumental one.

It is estimated that in U.S.A. nearly 35 million acre feet, or 40 percent of the volume of water diverted for irrigation is lost due largely to seepage from the canals before it reaches the farms.

Part of the water that seeps from the higher canals flows into nearby, lower canals. Also, part of the water returns to the creeks and rivers and is again diverted for irrigation of lower lands. However, more efficient conveyance of water is a problem of great concern to the engineer as well as to the public. Excessive seepage losses are costly in many ways. One of the great disadvantages of excessive seepage losses from canals is soil water logging, thus making millions of acres of land non-productive. It is, therefore, very important that the engineer and the public give greater attention to the provision of facilities for efficient water conveyance.

Many materials and methods for canal lining have been developed, yet a substantial number of canals are not lined—not more than 5 percent are lined. Certainly the need for lining of canals to reduce seepage is very great in many countries.

During 1955 and 1956, the author visited irrigation projects in Africa, India, Iran, Iraq, and Pakistan where the soils of very large areas of irrigation project lands have become waterlogged in only 25 to 50 years after the irrigation water was first provided and applied.(10,13,14,15,16,18) Determinations of water conveyance efficiencies and of water application efficiencies on these projects, though very important to soil and water conservation, are yet to be developed; and these determinations are urgently needed.

The International Commission on Irrigation and Drainage (ICID) Third Congress held in San Francisco during May, 1957, considered Canal Lining as one of the major questions. The 20 papers on Canal Lining presented by engineers from 11 countries demonstrate the world realization of needs for lining of irrigation canals to assure efficient conveyance of water. They also add information concerning methods and materials for canal linings.

It was encouraging to the author to find in January, 1956, concrete lining for new canals on the Karkheh Project in Iran as illustrated in Fig. 4. Efficient water conveyance on this project is very essential.

Water Application Methods and Problems

One of the major world problems in soil and water conservation in arid regions is to find how economically to apply adequate depths of irrigation water to the soils in each irrigation, and also how to prevent the application of excessive depths of water which cause excessive deep percolation, shallow water tables, and waterlogging of root-zone soils, salinity and alkali problems, and sterilization of soils.(8) Irrigation water is applied to the surface of the soil by flooding, in furrows, and by sprinkling. Major questions confronting the engineer are: how to best prepare the lands for irrigation, and how to irrigate the soil efficiently. Land leveling for irrigation by hand methods in India is illustrated in Fig. 5. Modern methods with modern machinery are urgently needed in many countries.

The orchard specialist and the agronomist have conducted many experiments in irrigation agriculture and irrigation of orchards, of alfalfa, of grains, and of other crops, but the engineer has not yet given enough attention to the IRRIGATION OF THE SOIL. The dominant factors which determine the appropriate depth of water to apply in each irrigation are soil texture, structure, and root-zone depth. Only very few soils can retain more than 1-1/2 inches depth of available soil water per foot depth of soil from one irrigation. Some soils retain less than 3/4 inches per foot depth of soil. In root-zone soils of 4-feet depth, the maximum water depth in a single irrigation should, therefore, not exceed 6 to 7 inches.

Great progress has been made during the past few decades in measuring the capacity of root-zone soils to store available soil water.

For example if:

D = the depth of root-zone soil, inches,

P_{ac} = the percentage of available water on the dry-weight basis or the field moisture capacity less the moisture percent before irrigation,

Figure 4. Concrete Lined Canal Recently Constructed on the Karkheh Project in South Western Iran

A_S = the apparent specific gravity of the soil, and

d = the depth of water in inches to fill the soil available water capacity.

Then $$d = A_s P_{ac} D \quad (1)$$

For a soil of 1.3 apparent specific gravity (A_S) having an available water capacity (P_{ac}) of 5 percent and depth of 60 inches, the depth of water needed, if spread uniformily would be, from equation (1)

Figure 5. Preparation of Land for Irrigation in Northern India by Hand Labor

$$d = 1.3 \times \frac{5}{100} \times 60 = 3.9 \text{ inches}$$

With modern equipment including tensiometers and related facilities, the elements in equation (1) can now be measured at reasonable costs.

The following elementary rational equation makes it easy to compute depths of water applied:

$$dA = Qt \quad (2)$$

When d = average depth of water applied, inches

A = area of land irrigated, acres

Q = the size of stream used, cubic feet per second, or (acre inches per hour approximately)

t = time required to irrigate the area, hours.

This equation should be used by farmers with the help of the engineer, in all irrigated countries of the world. It can be used in the irrigation of millions of acres in many countries with substantial advantage to the conservation of soil and water. A convenient and easy graphical method of solving this equation and thus finding the depth of water applied to a given farm area (acres) with a given quantity of water (cubic feet per second) in a selected time (hours) was developed by Garton[5] and is illustrated in Fig. 6 for English measurement units. This figure shows, for example, that a stream of 4 C.F.S. applied to a 31-acre tract of land for a period of 50 hours would cover the land to a depth of 6.5 inches. Also if 2 cubic feet per second are used for 40 hours to irrigate 10 acres, the depth is 8 inches.

Equations (1) and (2) are presented in the Author's text book, "Irrigation Principles and Practices"[9] 1932, and also in the Second Edition of 1950. This book has been translated and published in Yogoslavia and Russia. It will be published soon in China.

In the metric units of liters per second, centimeters depth of water applied, and areas in Hectares A the equation is:

$$27.8\ Qt = dA$$

A popular and unfortunate slogan among pioneer irrigators of the West was: "More Water, More Crops." This led to inefficient and wasteful application of water to thousands of farms. The results of many measurements of the water-application efficiency and its relation to the depth of water applied are presented in Fig. 7. Note that with a depth of less than 5 inches, the efficiency was from 45 to 85 percent; but that when the depth was more than 20 inches, the efficiency was less than 20 percent.

These low water application efficiencies do not contribute to soil and water conservation. They do contribute to losses of soils, of water, and of plant food.

The number of irrigations each year is a factor of great importance in the necessity for special attention of the engineer toward higher efficiencies in water application. Assume, for example, that the average area of the world irrigated farm is 100 acres. The world would then have 3 million irrigated farms. As an average assume, that each farm is irrigated 5 times per year. On the basis of these estimates of farm area, and number of irrigations, the farmers in the 60 countries of the world that depend on irrigation would apply 15 million irrigations each year. This great number of water applications each year helps to demonstrate the urgent need of worldwide assistance by the engineer to measure the depths of water applied 15 million times and assure efficient application of irrigation water to the soils.

The time rate of water application, in relation to the soil permeability and infiltration rate, is of vital importance. When the flooding methods are used, if water is applied slowly to large fields, excessive deep percolation of water

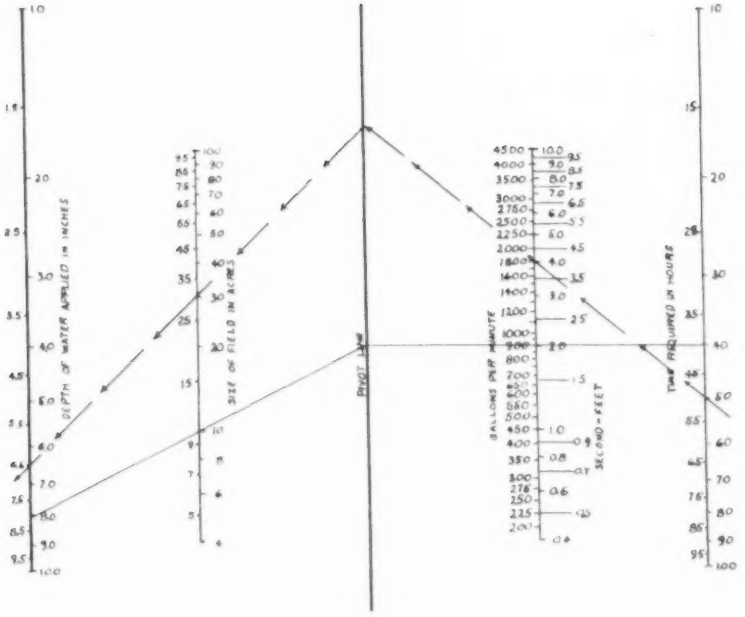
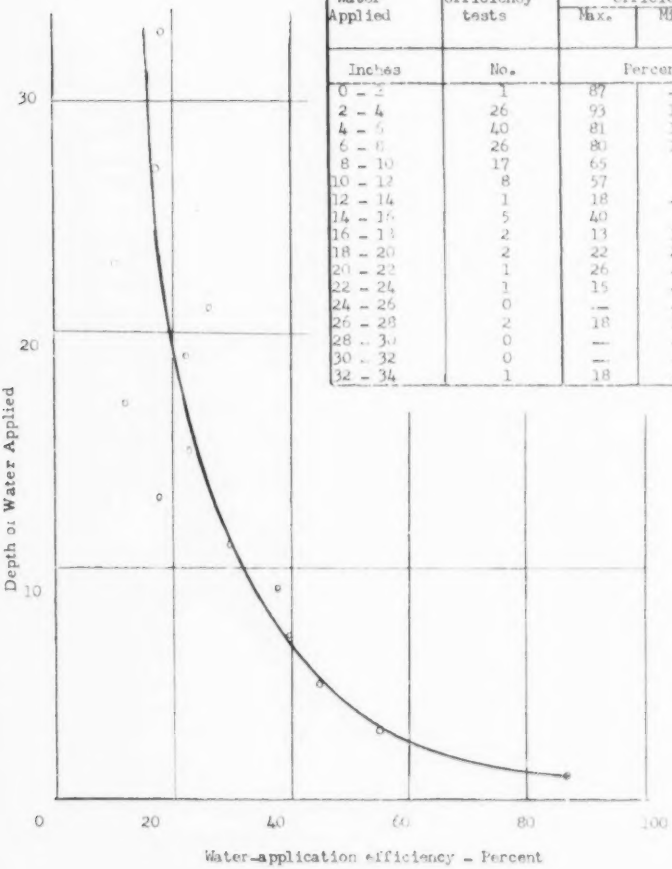


Figure 6. Nomograph for Finding Depth of Water Applied by Irrigation.(5)

through the soils will occur near the upper end of the field. As shown in Table 4 and Fig. 8, this will greatly decrease the water application efficiency. On the other hand, large irrigation streams applied to small fields tend to cause excessive surface runoff losses and low application efficiencies.

The effects of applying water at low rates to long border strips in Idaho are shown in Table 4.

For the clover tract when the time rate of water application (q/A) was 5.8 cubic feet per second per acre, an average depth of 8.1 inches was required to cover the area, and when q/A was reduced to 0.8 cubic feet per second per acre, the average depth required was 20.2 inches. If we assume



Depth of Water Applied	Number of efficiency tests	Water application efficiency		
		Max.	Min.	Mean
Inches	No.	Percent		
0 - 2	1	87	—	87
2 - 4	26	93	13	55
4 - 6	40	81	11	45
6 - 8	26	80	16	40
8 - 10	17	65	9	38
10 - 12	8	57	8	30
12 - 14	1	18	—	18
14 - 16	5	40	6	23
16 - 18	2	13	11	12
18 - 20	2	22	21	22
20 - 22	1	26	—	26
22 - 24	1	15	—	15
24 - 26	0	—	—	—
26 - 28	2	18	16	17
28 - 30	0	—	—	—
30 - 32	0	—	—	—
32 - 34	1	18	—	18

Figure 7. Water Application Efficiency Studies.

the available water holding capacity depth as about 4 inches, as illustrated in equation (1), then the water application efficiency would be 50 percent for the time rate of 5.8 C.F.S. per acre and 20 percent for the low time rate of 0.8 C.F.S. per acre. The readers can make similar comparisons for the results of the irrigation of the alfalfa tract shown in Table 4.

The Montana Agricultural Experiment Station in 1957 gave special attention to research concerning "Irrigation Application Efficiencies," and

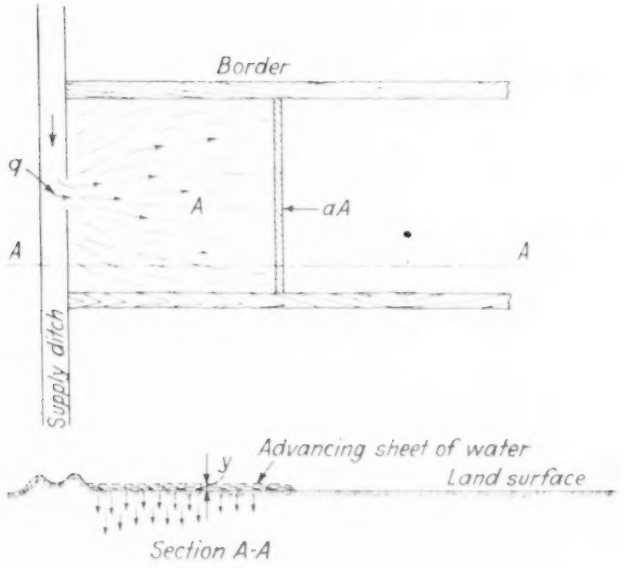


Figure 8. Illustrating irrigation water being applied to a border strip, and how the water moves forward to cover a small area, dA, in a short time, dt, and also how it percolates into the soil of the upper part of the strip.

developed an equation for computing the required size of stream to apply the desired depth of water to a border strip of given size and slope and with soils of known infiltration rates. In 13 field tests on 3 days with this basic equation, the average depths of water applied were 4.5, 3.0, and 4.4 inches respectively. The maximum depth in the 13 tests was 5.6 inches and the minimum was 2.6 inches.

The results of these studies and tests when published will be of special interest to the engineer who is contributing toward worldwide improvements in soil and water conservation.

CONCLUSIONS

The author's long-time studies of soil and water conservation as related to irrigation and drainage problems and progress in U.S.A. together with short-time studies in Africa, Brazil, Canada, India, Iran, and Puerto Rico constitutes the bases for the conslusions that:

1. The engineer has vital and great responsibility to society in irrigation and drainage for worldwide soil and water conservation.

TABLE 4 - Time and Depth of Water Required to Irrigate Two Strips of Land Near Rigby, Idaho, when Water as Applied at Different Time Rates.

1 No. of Divisions Covered in One Run	2 Length of Strip Covered, Feet	3 Area of Plot Covered, Acres	4 Time of Application q/A, C.F.S. per acre	5 Time Required, Hours	6 Average Depth of Water Required to Cover Area, Inches
		(a) Clover Tract			
1	337	0.383	5.8	1.37	8.1
2	674	0.767	2.9	3.20	9.5
3	1011	1.150	1.9	5.20	10.3
4	1348	1.534	1.5	7.70	11.4
5	1685	1.917	1.2	10.70	12.7
6	2020	2.300	1.0	16.70	16.5
7	2359	2.684	0.8	23.70	20.2
		(b) Alfalfa Tract			
1	327	0.70	10.0	0.75	7.4
2	654	1.41	5.0	1.66	8.2
3	980	2.13	3.3	2.83	9.2
4	1307	2.88	2.4	4.25	10.2
5	1634	2.63	1.9	6.25	11.9
6	1960	4.39	1.6	8.25	13.0
7	2287	5.17	1.4	10.50	13.9
8	2566	5.72	1.2	13.25	16.0

2. The engineer must have the strong and active support of the agronomist, botanist, soil chemist, and also of legislative, administrative, and judicial officials—Presidents, Kings, Queens, Ministers, Directors, Judges, Jurys, etc. to solve soil and water conservation problems for world welfare.

3. Continued world cooperative activities as represented by the ICA, United Nations, ESCO and FAO, ICID, and other similar agencies are vitally important to progress in conservation.

4. In nearly all of the arid-region countries there are urgent needs for training a large number of irrigation and drainage engineers to extend and improve irrigation system efficiencies, prevent and correct water logging of soils, establish and maintain effective drainage systems; and thus contribute to soil and water conservation.

5. The challenge of perpetuating agriculture and civilization confronts also statesmen and scientists. They must enlarge the development of the sciences, and their application to agriculture. They must allot liberal proportions of their funds, and their agencies to studies of methods of water conveyance and of application of water to soils that will assure soil productivity, prevention of soil erosion, and mastery of the salinity and alkali problems.

6. The U.S.A. contributions in technical cooperation have been substantial and

have advanced the standard of living, provided equality of opportunity, and promoted friendship and peace in many countries. The engineer should endorse and support this statement made by President Eisenhower:

> "We have wanted a world in which we might live in peace and confidence. And in striving toward this goal, we have understood that to help others was often the best way for ourselves to advance."

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IRRIGATION IN THE HUMID AREA[a]

Closure by E. A. Kimbrough, Jr.

E. A. KIMBROUGH, JR.[1]—The discussion by Mr. Blaney was very interesting. From his remarks, it becomes apparent that the writer did not make a specific statement as to the intent of the paper as to the type of crops on which the major emphasis would be placed. The writer was intending to show those problems centered on extensive field crops such as cotton, corn, soybeans and others. The theoretical calculations as to water requirements have been more satisfactory in citrus and vegetable crops than with the extensive field crops such as pastures, cotton and corn. The reason for this earlier success of citrus and vegetable crops is due to their sensitivity to drought conditions because of the root system and tender nature of the vegetative growth.

The writer was aware of the method mentioned estimating consumptive use of water. This is a very valuable tool for the design engineer in calculating the supplemental water that must be available provided the demand exists. The problem that plagues the irrigator in the humid area is predicting when the need exists and for what length of time the need will continue until satisfied by rainfall.

The writer has experienced very often irrigating a crop and having a heavy rain within twenty-four hours or less. Adequate irrigation followed by heavy rains has caused serious damage to the crop. The greatest problem is not in the calculation of the demand quantity, but in predicting accurately the length of an existing drought period. This type of prediction lies in the realm of "weather forecasting" and not in the hands of the irrigation engineer.

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a. Proc. Paper 1352, September, 1957, by E. A. Kimbrough, Jr.

1. Asst. Agri. Engr., Dept. of Agri. Eng., Mississippi State College, State College, Miss.

A GRAPHICAL SOLUTION OF FLOW IN EARTH CHANNELS[a]

Closure by Isidro D. Cariño

I. D. CARIÑO,[1] J. M. ASCE.—There is general agreement in the advantages brought about by the use of graphical solutions to recurring problems. Various approaches have been designed by engineers to meet their particular needs.

The 2 graphs presented by Mr. Cox in his discussion no doubt meet the requirements of the U. S. Army Engineer Waterways Experiment Station for rapid preliminary design work where different channel shapes and sizes, roughness values, and slopes are to be investigated. The area A in the first equation apparently had been overlooked since it appears in the right hand side of the equation for C_K.

Messrs. Kolupaila and Kennedy contributed an interesting presentation and discussion of a graphical solution of Manning's formula. The writer concurs that some additional data can be incorporated in the nomogram. Mention was made of the most efficient section which will require the least excavation. Theoretically, it will lead to the most economical design. However in practice the terrain on which the canals will be constructed frequently is an important factor to consider and the so-called efficient section may not turn out the most economical design. In the Philippines it has been our experience that it is more economical to use $\frac{b}{d} = 2.5$. Such a section increases the amount of excavation to some extent. However this increase in excavation is utilized in building up the embankment that is generally required on the side of the canals. The excavation from the canal when the minimum cross-sectional area is used is usually not sufficient to cover up the need for embankment materials and since it costs more to borrow soil materials from other sources the increase in excavation by use of a $\frac{b}{d}$ ratio of 2.5 generally leads to a more economical design. Since these graphs were constructed primarily for use in the canal design in the Bureau of Public Works in the Philippines, the conditions meeting our needs were specifically adopted.

The discussion of Messrs. Cox, Kolupaila, and Kennedy are very well appreciated.

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a. Proc. Paper 1360, September, 1957, by Isdro D. Cariño.

1. Chief, Planning and Programming Unit, Irrigation Division, Bureau of Public Works, Philippines.

COMMON ERRORS IN MEASUREMENT OF IRRIGATION WATER[a]

Closure by Charles W. Thomas

CHARLES W. THOMAS,[1] M. ASCE.—The three formal discussions to the paper are very gratifying to the writer. He also wishes to take this opportunity to thank those who did not prepare discussions for publication, but who have commented verbally and by direct correspondence.

First, attention should be drawn to errors which appear in the original paper.

	As printed	Should read
Page 1362-4, Table 1, heading of second column, % error	$\frac{Q'-Q \times 100}{Q}$	$\frac{Q'-Q}{Q} \times 100$
Page 1362-6, Table 2, heading of fifth column, % error	$\frac{Q'-Q \times 100}{Q}$	$\frac{Q'-Q}{Q} \times 100$
Page 1362-17, Table 4, heading of fourth column, % error	$\frac{K-K_{oo} \times 100}{K_{oo}}$	$\frac{K-K_{oo}}{K_{oo}} \times 100$
First entry in fourth column	5.6	5.1

Mr. Starosoloszky has extended the discussion of items covered briefly in the paper. He has further emphasized the remarks by the author regarding the necessity for obtaining continuous records or representative head observations if accuracy is to be maintained. It is unfortunate that adequate information is not included to permit a better understanding of the supporting arguments. Presumably, each of the four curves in the three families of curves shown in Fig. 1 represents a different daily percentage variation in differential head at the Venturi meter. However, since there is no indication on the curves as to the assumptions made in calculating each one, the value of the figure in supporting the argument is considerably reduced.

In the case of a weir, the discharge varies more rapidly than the head. The relationship as given by many weir formulas shows that the discharge varies

a. Proc. Paper 1362, September, 1957, by Charles W. Thomas.

1. Hydr. Engr., Bureau of Reclamation, U. S. Dept. of the Interior, Denver, Colo.

as the three-halves power of the head. Therefore, the volume of discharge obtained by reading the gage at intervals and averaging the readings will give a discharge somewhat less than that actually passing the weir.

If an initial head of zero (H_o) and a uniform rise to a depth H_2 at the end of time interval T are assumed, Horton[1] has shown that the ratio of discharge by integration is

$$\frac{\text{Volume by average head}}{\text{Actual volume}} = \frac{(1/2)^{3/2}}{2/5} = 0.884$$

or the true discharge = 1.13 times the discharge obtained by using the average head for the two readings taken at the beginning and end of the period.

This percentage of error will be the same regardless of maximum head (H_2) and for a rising or falling stage if the initial head (H_o) is zero. The error resulting from computation of discharge using the mean head will decrease as the ratio H_1/H_2 increases if there is an initial depth of flow H_1 over the weir. The percentage of error will decrease as the number of readings per time interval are increased and approach zero as for continuous records.

Short period surface fluctuations approach wave conditions. It has been shown by Professor Gibson[2] that wave disturbance increases the discharge over a weir. When waves are present, the discharge may be expressed as 1 + K times the discharge under the same observed head with undisturbed water in the approach channel. The values of K derived by Professor Gibson are:

> With waves of sinusoidal form, and a thin crested rectangular weir, $K = 0.19\ (a/H)^2$ and a 90-degree Vee-notch weir, $K = 0.94\ (a/H)^2$ where a is equal to one-half the wave length
>
> With waves of trochoidal form the effect is less than with sinusoidal waves. The value of K for rectangular weirs varies from $0.070\ (a/H)^2$ to $0.182\ (a/H)^2$ for ratios of wave length over wave height varying from 3.14 (sharp crested wave) to 15, respectively. For the same range of length-height ratios, the value of K varies from $0.50\ (a/H)^2$ to $0.92\ (a/H)^2$, respectively, when applied to a 90-degree Vee-notch weir.

As in many of the instances pointed out in the paper, the error is negative. Thus, when waves are present, more water is delivered through the weir notch than is indicated by gage readings of the mean water level.

Some clarification is apparent from the remarks made by Mr. Kolupaila. The purpose of the original paper was to point out some of the reasons why measurements made in connection with the conveyance and delivery of irrigation water may not be as accurate as assumed and to present some idea of the order of magnitude of the error to be expected from a few of the more common deviations from accepted practice in the use of standard devices generally used in the field. The writer is fully aware of the hundreds of valuable papers and discussions which have been written on the subject of weirs. To this long list many new papers are being added each year. This device has probably been the subject of more hydraulic laboratory investigations than any other development, be it for flow measuring or for other use. To list only the subject and author of these writings on weirs would occupy far more printed pages than the paper. A similar listing of references to the other field measurement devices discussed would be extremely lengthy. It should be

noted that the word "references" was used in the paper and not "bibliography." To a technologist working in a large university or for a large firm where an extensive library is available, a bibliography may be a rare gem, but dross to the engineer in a small office or in the field. For him, the few items having an immediate practical bearing on his problem must be cited and summarized.

American engineers are generally well aware of the great value of writings done in other countries. This is evidenced by the fact that many of the articles of European engineers on weirs and other subjects have been studied, translated in full or abstracted and the contents are quite well known. One example is Dr. Hailer's thesis, given as Reference 4 on page 1615-27. This excellent writing has been translated in full and published by ASME.(3)

The Schoder and Turner paper with the many excellent discussions and references(4) may be considered an international symposium on sharp crested weirs and a review of the earlier European writings.

It appears that an abundance of information rather than a deficiency contributes to the confusion in the spelling of the name of the inventor of the trapezoidal weir having a slope on the sides of 1 horizontal to 4 vertical. Examination of 26 references immediately available to the author, without search or recourse to the library, reveals that eleven spell the name CIPPOLETTI, ten use CIPOLLETTI, three use CIPOLETTI and one uses CIPPOLETI. This very limited examination shows that continental European writers prefer CIPOLETTI while those from Great Britain prefer CIPPOLETTI. The spelling by American writers is almost equally divided between CIPPOLETTI and CIPOLLETTI. The references examined left no doubt regarding the type of weir referred to. However, the confusion in spelling certainly should be corrected.

The comments by Mr. Balloffet are most welcome additions to the paper. The statement "the error of measurement begins with an improper selection of the measuring device," certainly merits extensive consideration. Selection of the proper means of measurements to best fit the physical conditions at the site would solve many of the operating problems. On the side of economics, the author prefers to include under requirements for a measuring device, as given by Mr. Balloffet, under e, initial costs and operation and maintenance costs.(5) If the latter costs are included, perhaps Mr. Balloffet will wish to modify his statement, "weirs fail to meet all but perhaps the fifth of these conditions," (e. is inexpensive) "in most common instances." To maintain a weir installation in such condition that it will give reasonably accurate results is usually a significant item of expense.

A Venturi flume, as pointed out by Mr. Balloffet, is capable of accurately measuring a wide range of discharges and for this reason should be more extensively used. This type of device has been subjected to extensive study and is recognized on an international basis. Dr. Engel(6,7) has established some interesting flow relationships in these devices.

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DRAINAGE IN THE MISSISSIPPI RIVER VALLEY[a]

Discussion by Clyde P. Cass, Jr. and Richard T. Shen
Closure by Louis W. Herndon

CLYDE P. CASS, JR.,[1] M. ASCE and RICHARD T. SHEN.[2]—Mr. Herndon, under the heading "Project Development" has given drainage formulas used by the Soil Conservation Service and the Corps of Engineers in the design of drains in the Mississippi Watershed.

Mr. E. W. Lane with the help of Mr. Pu of Taiwan, Free China,[3] has made detailed studies of drainage problems and practices in this area, and has developed a workable formula for the drainage of flat lands in the Mississippi Watershed, which takes into consideration a 5-year frequency of rainfall in twenty-four hours.

The formulas given by Mr. Herndon under Project Development as used by the Soil Conservation Service and the Corps of Engineers in the design of drainage ditches are plotted on the Lane-Pu graph as shown below.

It is interesting to note the close agreement of the two separate sets of formulas. This correlation serves to support the soundness of both empirical approaches. The Lane-Pu drainage formulas were developed by a synthetic analysis of all the available drainage formulas and data in the area. The formulas used in this derivation are listed below as to area and source and conditions under which they apply.

1. $Q = \left(\frac{35}{\sqrt[6]{M}}\right) M = 35 M^{0.83}$ Cypress Creek, Arkansas, drainage district, Desha and Chicot Counties.

   Total area of district is 460 square miles, being classified as Mississippi bottom land. Cultivated area comprises not more than ten per cent with cotton farming the main crop. Top soil is Mississippi alluvium. Maximum rainfall on record is 5.8 inches in twenty-four hours. (Miami Conservancy District Tech. Report No. 5)

2. $Q = \left(\frac{20}{\sqrt{M}} + 3.63\right) M$ C. G. Elliott, Upper Miss. Valley

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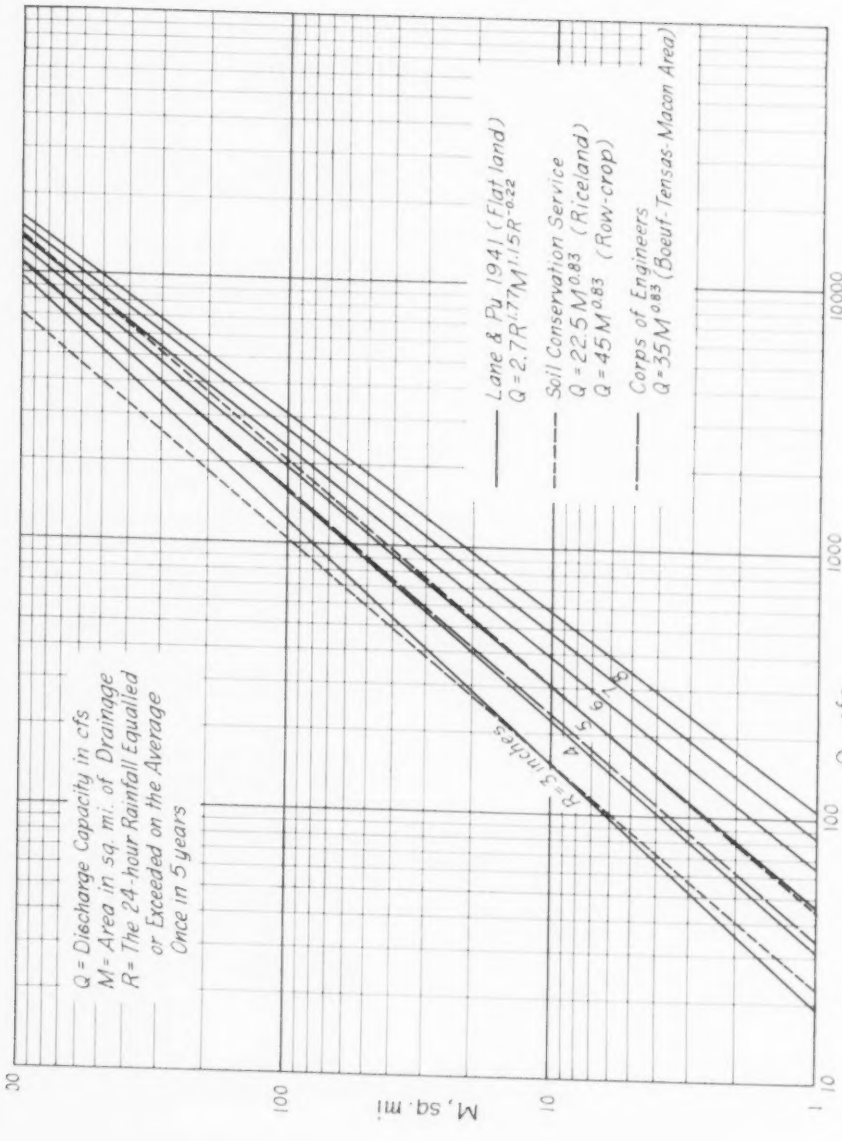
a. Proc. Paper 1363, September, 1957, by Louis W. Herndon.

1. Agri. Engr. (Soil Conservation Service, S. Dak.), Graduate student, Irrig. Eng., Colorado State Univ., Ft. Collins, Colo.
2. Asst. Research Engr., Colorado State Univ. Research Foundation, Ft. Collins, Colo.
3. Q. C. Ayres, Agriculture Eng. Dept., Iowa State College and L. L. Hindinger (deceased, formerly of Morgan Eng. Co.) contributed to the studies made by Mr. Lane and Mr. Pu.


Q = Discharge Capacity in cfs
M = Area in sq. mi. of Drainage
R = The 24-hour Rainfall Equalled or Exceeded on the Average Once in 5 years
Lane & Pu 1941 (Flat land)
Q = 2.7R^1.77 M^1.15 R^-0.22
Soil Conservation Service
Q = 22.5 M^0.83 (Riceland)
Q = 45 M^0.83 (Row-crop)
Corps of Engineers
Q = 35 M^0.83 (Boeuf-Tensas-Macon Area)
R = 5.2 inches
M, sq. mi.
Q, cfs
20
100
10
1
10
100
1000
10000

3. $Q = \left(\frac{24}{\sqrt{M}} + 6\right) M$ — C. G. Elliott, Little River, Northwestern Arkansas.

Total area of district is 1000 sq mi. Topography is nearly flat, wooded plain, consisting of soil alluvium deposited by Miss. River. Maximum rainfall is 5.2 in. per 24 hrs.

4. $Q = \left(\frac{38}{\sqrt{M}} + 8\right) M$ — Cache River drainage district.

5. Taken from curve — J. T. Stewart, Red River Valley, N. D.

U. S. Dept. of Agriculture Bulletin 189, Aug 1907.

6. $Q = 12\, M^{0.9}$ — J. T. Fanning, Red River Valley, Minn.

U. S. Dept. of Agriculture Bulletin 1017, 1886.

7. $Q = \left(\frac{1000}{M} + 15\right) M$ — Big Black River, Miss. U. S. Dept. of Agriculture Bulletin 181, 1915.

Drainage area is 150 sq. mi., consisting of bottom land from 1/2 to 2-1/2 miles wide, bordered by rough, rolling land. The soil is composed of a silty loam underlain by clay. Maximum rainfall is 6.1 in. per 24 hrs.

8. Taken from curve

U. S. Dept. of Agriculture Bulletin 244, Belgoni drainage district, Wash Co., Miss.

9. $Q = \left(\frac{28}{\sqrt{M}} + 7.2\right) M$ — Morgan, St. Francis Valley, Ark. Low flat alluvial land.

(Drainage Project in Northeastern Ark., Office of Experiment Stations, Circular 86, pp. 20).

10. $Q = \left(\frac{90}{\sqrt{M}} + 10\right) M$ — Mead, tentative formula for a Louisiana district of drainage.

No consideration is given for storage in bayous and ditches. Maximum rainfall is 6.1 in. per 24 hrs.

11. $Q = \left(\frac{673}{19.2 + \sqrt{M}} - 11.3\right) M$ — C. G. Elliott, Central Ill.

12. $Q = \left(\frac{12}{1 + \sqrt{M}}\right) M$ — F. C. Elliott, Everglades drainage district, Florida (Eng. News-Record, July 28, 1921)

This formula gives satisfactory drainage lay-out for muck land.

13. $Q = \left(\frac{3400}{M + 50} + 5\right) M$ — Mead, Tentative formula for certain districts in Florida Everglades. (Mead's Hydrology, p. 588)

14. $Q = \left(\frac{45}{\sqrt{M}} + 14\right) M$ Revised formula for Little River, Northwestern Arkansas.

By the use of the above formulas, the Lane-Pu drainage formula

15. $Q = 2.7R^{1.77}M^{1.15R^{-0.22}}$ was derived by the following steps:

Where: Q is discharge in cfs
R is the maximum rainfall in 5 years frequency in inches per 24 hours
M is the drainage area in square miles.

Step I

Obtain all the available data relating to the subject. These data are written in different forms of tables and articles.

Step II

Plot the data obtained on log-log paper with discharge Q as abscissa and drainage area M as ordinate.

Step III

Plot all the points on log-log paper with Q as abscissa and R as 5-year frequency maximum rainfall data as ordinate, for different values of drainage areas.

Step IV

Draw one straight line through points which represent "good drainage" from each size of drainage area.

Step V

By the use of curves obtained in Step IV, plot on log-log paper discharge Q as abscissa and Area M as ordinate for different values of maximum rainfall of 5-year frequency.

Step VI

From the curves of Step V obtain their intercepts with the X-axis and their slopes. Plot these on log-log paper as ordinates with maximum as abscissa. Draw the fitting straight lines for them. (Slope equals $1.15R^{-0.22}$; Intercept equals $2.7R^{1.77}$)

Step VII

Adjust the lines in the graph of Step V to fit the results from Step VI to produce the final graph.

Step VIII

From the curves obtained in Step VI, the equations of intercepts and slopes when combined from log-log paper give the following equation:

$$Q \text{ equals } KM^n \text{ equals } 2.7R^{1.77}M^{1.15}R^{-0.22}$$

For other discussions on drainage formulas refer to Mr. George Pickles drainage article in Handbook of Applied Hydraulics by C. V. Davis, Section 22 page 1015. In this article a comparison of runoff curves which have been used in design of drainage channels in different sections of the United States is illustrated.

For detailed information about the Soil Conservation Service drainage formulas refer to: SCS Drainage Engineering Handbook, Section 16. SCS Hydrology Handbook will give runoff coefficients to use in design of drainage ditches for specific soils and land use requirements.

LOUIS W. HERNDON.[1]—The rate of runoff for which agricultural drainage systems should be designed is determined by a number of considerations. Maximum 24-hour rainfall to be expected once each 5 years is one factor to consider. Size of drainage area is important—the rate of runoff per square mile for design decreases as the area increases.

These factors have been studied by many engineers and formulas developed which suited the particular requirements. There are other considerations which are not specifically identified in the formulas studies by Messrs. Cass and Shen. These are topography, soils, land use, and crops to be grown. All are important in selection of a drainage coefficient.

Undoubtedly all of these factors were considered by the men who developed the formulas listed in the discussion by Messrs. Cass and Shen. Actual stream-flow measurements have also been a deciding factor in formula development. The result is somewhat different formulas for use in specific areas.

The Soil Conservation Service has given a great deal of study to the development of runoff curves which will give adequate agricultural drainage in those areas where it is needed. There are at least six different curves which have been developed for frequent use in the alluvial valley of the Mississippi River. They are all derived from adaptations of the basic formula $Q = CM^n$. A curve is selected to give good drainage to the particular area giving due consideration to climate, topography, soils, land use, crops, and the degree of development within the watershed. Frequently two or more curves will be used in the same watershed in order to give different degrees of drainage to separate parts of the watershed.

1. Drainage Engr., U. S. Dept. of Agri., Soil Conservation Service, Ft. Worth, Tex.

Observations of the successful drainage accomplished by the use of these curves over a period of many years have proved their suitability.

WATER USE IN INDUSTRY[a]

Discussion by Frederick L. Hotes
Closure by Ray L. Derby

FREDERICK L. HOTES,[1] M. ASCE.—The relative magnitude of the industrial requirements for water, as compared to other uses in the United States, is concisely presented in the summary table on the first page of this paper. The writer desires to supplement and extend these basic figures, by means of a different approach that has proved to be very effective from the standpoint of water resources planning in the state of California, and has also served to emphasize the intensive concentration of many industrial uses.

The alternate method of presentation to be herein discussed is based on the "area-depth" method. In this approach, the total volume of water used during a unit of time (the most common unit being one year), is expressed as the depth of water in feet that would cover the land concerned if the volume of water used could be spread uniformly over that land. This method is universally employed by engineers, hydrologists and others, to express water use of non-urban lands, but its use for urban areas has been much more limited, even though known for some time.(1,2) It is particularly useful when studying regions that embrace both agricultural and urban lands, and in which the areas of urban land are being expanded at the expense of agricultural lands. It was the primary method used by the California Division of Water Resources in making probably the most comprehensive survey ever made of a large area (100,690,000 acres) embracing practically all types of water uses. The results of this survey, a determination of the "Water Utilization and Requirements of California", was published in June, 1955,(3) and was for conditions as of about 1950. In the large metropolitan areas such as the San Francisco Bay Area, Los Angeles, and San Diego, the population-saturation method was used to supplement the area-depth studies.

In these California studies the importance of industrial uses and needs received detailed attention. It was soon found that while there was much data available as to industrial needs expressed in units of production, and as per capita usage for industry, little was known about the total uses and needs of industry as a whole. Even industry did not have the answers. It was therefore necessary to make detailed surveys of water uses of all types, using water meter data, with corrections where necessary for supplemental sources of supply. Areas devoted almost exclusively to industry that were subjected to such studies included the Vernon and Terminal Island areas near Los Angeles, and the City of Emerville, near Oakland.

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a. Proc. Paper 1364, September, 1957, by Ray L. Derby.

1. Water Conservation Engr., Development & Resources Corp., New York, N. Y. Stationed in Ahwaz, Iran.

One study made in 1950 of some 107 industrial uses in Emeryville, covered the following types of industries.

Industrial Classification	Number of Industries
Chemical and Allied	11
Electrical Machinery	3
Fabricated Metal	15
Food and Kindred Products	11
Lumber and Products	1
Contractors	3
Distributors	26
Laundries	1
Machinery	9
Paper and Allied Products	6
Primary Metal Industries	1
Printing and Publishing	1
Textiles	1
Utilities	4
Rubber Products	3
Miscellaneous Manufacture	11
TOTAL	107

The average depth of water use for these industries was 7.2 feet per year. This depth refers to the net area occupied by industry inside its property lines, thus excluding city streets, sidewalks and parking strips. The range of use varied from 0.2 foot to 24.5 feet.

Some industries in the Bay Area used as much as 45 feet depth of water per year.

For the entire San Francisco Bay Region, an area of 2,538,000 acres, it was found to be convenient to classify industry into three subclasses.(4) "General industrial" uses included manufacturing, storage, transportation and wholesale distribution facilities. Industries with very minor water demands such as oil tank farms, explosive storage areas, and salt evaporation ponds were classified as "low water-using industrial". "Airfields and appurtenant facilities" were considered as the third class of industrial use. Areas and average water uses of these classifications in about 1950 were as follows:(5)

Industry Classification	Area in acres	Average water use in feet of depth per year
General	11,500	11.1
Low water-using	30,900	Practically Zero
Airfields	3,600	0.4

The above figures refer to water deliveries, and are not consumptive use.

For comparison, it should be noted that single dwelling residential areas have uses generally ranging from 2.2 - 2.5 feet.

The total area of all urban and suburban classifications in 1950 was about 225,000 acres. The needs of industry at that time, in this perhaps typical metropolitan area with a population of over 2,500,000, constituted 36.6 per cent of the total urban usage.

Different urban classifications were used in the Los Angeles and San Diego areas for better adaption to the local zoning ordinances and conditions, but the

general industrial average use, and the range of usage, was found to be about the same as in the San Francisco Bay Area. One fact that was quite evident was that even in these areas where water supply is generally acknowledged to be critical, and where water imports are made over great distances and difficult terrain, at considerable cost, many thriving industries exist that use great quantities of water. There is little doubt in the writer's mind but that this will always continue to be so, for as much as industry desires good water, in ample quantity and at low rates, the predominant influence of such business factors as sales market, climate, labor market and transportation, will, in a great many instances, outweigh the cost-of-water factor. It is fundamental, of course, that at least the required quantities of water must be available.

Two other types of water use within urban areas have much greater demands than is normally realized. Those are the downtown commercial areas, and the large hotels. The average commercial use in San Francisco was found to be 10 feet;(5) in the downtown commercial area of Los Angeles to be slightly over 10 feet;(6) and in the downtown commercial area of San Diego to be over 28 feet.(7) Large department stores often have water uses in the 30-40 foot range. Use in the San Francisco hotel area atop Nob Hill, site of the world-famous "Top of the Mark", was found to be almost 80 feet. A large hotel in downtown Los Angeles had a use of around 100 feet.

As water becomes more costly, industry and business will extend their efforts in re-use and reclamation of waters that in the past have been wasted. This will tend to decrease, or at least to hold near present levels, the intensity of net industrial demands. The author has cited several examples of successful achievements in this direction, and has also ably illustrated that the degree to which this will be done will depend primarily upon economics.

The writer wishes to conclude his remarks by presenting some condensed figures from the California Study(8) that give some indication of the tremendous development task ahead in order to supply the water needs of all types. While these figures are for a State that is presently (1958) the second most populous in the United States, and destined, according to many predictions, to some day rank number one in population, the relative proportions of each type of use may be of interest to those in other areas where agriculture, industry, and domestic demands are all increasing simultaneously.

Table I gives volume of water needed per year, and the per cent of the total volume for each category shown. A column has also been inserted by the writer to show the per cent distribution based on certain assumptions of cost. These latter figures result when the assumption is made that the cost of urban and suburban water is ten times that of water for irrigation or other uses. While this is an arbitrary assumption, it is believed to perhaps give a better indication of the true importance of domestic and industrial demands, since the latter can, and in most instances do, pay considerably more for water than does agriculture. Under this assumption, if irrigation water sold for $2 per acre-foot, urban water would sell for $20 per acre-foot (6 cents per thousand gallons).

A word regarding the meaning of "ultimate" as used in the table is perhaps in order. The California definition is:(9)

> "This is used in reference to conditions after an unspecified but long period of years in the future when land use and water supply development will be at a maximum and essentially stabilized".

TABLE I
CALIFORNIA WATER REQUIREMENTS

Type of Area	Present Requirements Year--1950 Population: 10,600,000			Ultimate Requirements Year--1??? Population: 42,000,000		
	Acre-Feet per Year	% of Total Volume	* % of Total Value	Acre-Feet per Year	% of Total Volume	* % of Total Value
Irrigated Lands and Farm Lots	19,250,000	91.2	53.5	37,246,000	81.7	32.0
Urban and Suburban Areas	1,654,000	7.8	46.0	7,827,000	17.2	67.5
Other Water Service Areas	224,000	1.0	0.5	493,000	1.1	0.5
TOTAL	21,128,000	100.0	100.0	45,566,000	100.0	100.0

* See text for assumptions of writer in deriving this figure.

It represents a potential growth that can reasonably be attained, but beyond which it is not presently conceivable that American civilization would require, or ask for, further intensification of population or facilities.

REFERENCES

1. Lee, Charles H., Water Consumption for Various Purposes in Terms of Depth and Area, Journal of the American Waterworks Association, Vol. 17, No. 2, February, 1927.
2. Gleason, George B., Consumptive Use of Water, A Symposium, Municipal and Industrial Areas, Trans. ASCE, Vol. 117, 1952, pp. 1004-1009.
3. Water Utilization and Requirements of California, Vol. I, Publication of State Water Resources Board, Bulletin No. 2, June, 1955. Sacramento, California.
4. Ibid., p. 85.
5. Ibid., Table 41, p. 92, p. 93.
6. Ibid., Table 90, p. 136.
7. Ibid., Table 91, p. 137.
8. Ibid., Table 170, p. 220, and Table 179, p. 226.
9. Ibid., p. 39.

RAY L. DERBY,[1] M. ASCE.—Mr. Hotes in his discussion has brought up some very interesting observations by his comments on the "area-depth" method for water use. This method, however, cannot be applied indiscriminately as there are many factors that must be given consideration.

The area-depth method is used by the Los Angeles Department of Water and Power in their general planning for future water use. However, in Los Angeles the area used generally includes all streets, parking, railroad sidings, etc., rather than excluding them as Mr. Hotes has mentioned. The Los Angeles Department of Water and Power feels that it is too great a refinement to consider excluding such areas in their planning since in many cases land is not subdivided and dimensions of streets, parking, etc., are not known.

The area-depth method is very useful in a general situation covered by a master plan, where areas are zoned as[2] R-1, A-1, M-1, M-2, M-3, etc. It gives a general idea of what water usage in a given zone may be. It is quite possible, however, that for instance in an M-2 zone many types of water-using industries would be involved and these industries could either be large or small water users, which would radically change the conditions of supply in a given area. Fire flows must also be given consideration over and above the quantities required in the area-depth method. The Q required for fire flow may be imposed upon the peak industrial load and require much larger mains. Reclassification of zones may preclude establishment of certain industries because of insufficient water supply or it may require the re-laying of mains to furnish the required quantity if these large water consumers are located within a given area.

Mr. Hotes mentions that even in areas where the water supply may be considered to be critical and water imports are made over long distances and difficult terrain at considerable cost, many industries exist that use great quantities of water. This may have been true in the past but it is the writer's belief that with imported waters costing more and more as they are brought from greater distances and with rising construction costs, it will be necessary in semi-arid areas to curtail industries which are large users of water and encourage them to settle in other areas where water supply and waste disposal problems will be much easier to solve even though the areas may be somewhat farther removed initially from advantageous labor and sales markets.

Mr. Hotes in his table bases certain costs on the assumption that urban and suburban waters will cost ten times irrigation water. This assumption which may have been valid in the past may not be necessarily so in the future in areas where imported water constitutes a large percentage of the available supply. Imported water has a minimum fixed cost and its selling cost should be the same to all. This of course means that in these areas irrigation use of water will ultimately disappear since the cost will be too high for its economical use. Unless for some specific reason the irrigation cost is still kept low (below the cost of imported water), this differential or loss must be subsidized by higher cost of water to the domestic or industrial user, or by an undesirable hidden tax subsidy.

In the ultimate consideration, industries and their water use must still be given individual consideration and their location must be predicated upon evaluation of all factors involved.

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1. Prin. San. Engr., City Dept. of Water & Power, Los Angeles, Calif.
2. These zoning classifications may not be used nationally. They mean agricultural, residential, manufacturing, etc.

TEAMWORK IN THE SOLUTION OF WATER PROBLEMS[a]

Discussion by Alfred R. Golze

ALFRED R. GOLZE,[1] M. ASCE.—Mr. Harvey O. Banks in his thought-provoking paper on "Teamwork in the Solution of Water Problems," has drawn a good picture of the necessity for all authorities to work together in developing the maximum gainful use of the limited water resources of the Nation. He utilizes the current California water supply situation as a demonstration of the problems that demand immediate attention.

Certainly any one who has been long engaged in any phase of water resources development cannot but agree with Mr. Banks' statements on the balanced use of water, directed to the maximum yield from each development, which should reflect not only the direct economic benefits but also the more intangible benefits.

Mr. Banks suggests that there are four aspects to the teamwork approach to solution of water problems relating first to the uses of water; second to coordinating the various agencies who plan, construct and operate water development projects; third, to the professional and scientific personnel engaged in research and; fourth to the professional and technical personnel who work with water on the one hand and the general public on the other hand. There is a close relationship between the second and fourth phase which at the Federal level, for example, often functions as one phase or aspect.

Mr. Banks recognizes that to do a team job, leadership must be provided. His paper does not, perhaps, give the full emphasis to that point nor does he treat fully the factors involved in any plan involving the Federal Government.

There is a well-recognized maxim that in any undertaking in which the Federal Government participates, through the contribution or direct utilization of Federal funds, the Congress requires the appropriate Federal agency to be responsible for the proper expenditure of such Federal funds. In meeting this responsibility the Federal agency frequently assumes a dominant role in the activity. This often is the reason why cooperative plans involving the Federal Government financing, end up with Federal leadership, even though on a percentage basis the Federal participation may be in the minority.

The attitude of Congress is well demonstrated by the provisions in the 1958 edition of the Rivers and Harbor and Flood Control Bill,[2] wherein a Federal financial contribution to the California Water Plan is authorized in the following language:

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a. Proc. Paper 1497, January, 1958, by Harvey O. Banks.

1. Asst. Comm., Bureau of Reclamation, U. S. Dept. of the Interior, Washington 25, D. C.

2. Sec. 204, S. 3910, Flood Control Act of 1958.

"Sec. 204. That, in recognition of the flood-control accomplishments of the multiple-purpose Oroville Dam and Reservoir, proposed to be constructed on the Feather River by the State of California, there is hereby authorized to be appropriated a monetary contribution toward the construction cost of such dam and reservoir and the amount of such contribution shall be determined by the Secretary of the Army in cooperation with the State of California, subject to a finding by the Secretary of the Army, approved by the President, of economic justification for allocation of the amount of flood control, such funds to be administered by the Secretary of the Army: Provided: That prior to making the monetary contribution or any part thereof, the Department of the Army and the State of California shall have entered into an agreement providing for operation of the Oroville Dam in such manner as will produce the flood-control benefits upon which the monetary contribution is predicated, and such operation of the dam for flood control shall be in accordance with rules prescribed by the Secretary of the Army pursuant to the provisions of section 7 of the Flood Control Act of 1944 (58 Stat. 890): Provided further, That the funds appropriated under this authorization shall be administered by the Secretary of the Army in a manner which shall assure that the annual Federal contribution during the project construction period does not exceed the percentage of the annual expenditure for the Oroville Dam and Reservoir which the total flood-control contribution bears to the total cost of the dam and reservoir: And provided further, That, unless construction of the Oroville Dam and Reservoir is undertaken within 4 years from the date of enactment of this act, the authority for the monetary contribution contained herein shall expire."

The principle of Federal direction following Federal financing is a plain fact of life that has to be considered in any planning of water resources development in this country, so much of which seems to be beyond the means of non-Federal agencies to finance. The writer, however, agrees with Mr. Banks that the teamwork approach is the only solution to our complex maze of engineering and economic activity associated with water resources development if we can solve the first problem, how to develop the desired teamwork. Federal leadership is already strongly apparent in the water resources development field and will continue not so much because of any desire for Federal supremacy by Federal officials but because the inter-basin and inter-state problems are being worked out under compacts authorized and approved by the Congress and with financing provided in whole or in part by the Federal Government.

In the opinion of the writer, the work will go forward best for all concerned if all levels of activity associated with water resources development can learn to work together at each level, taking full responsibility for its own area of interest and providing proper support and direction to the next higher level whether it be county, state, or Federal Government. Mr. Banks recognizes this when he calls for development of the California Water Plan under the leadership of the State, but the State can lose leadership to the Federal Government if too much assistance is furnished by Uncle Sam.

In support of Mr. Banks' recommendations, the writer also suggests that proper water resources development cannot be obtained if there is a continued effort by various interests to play off one Federal agency against the other

seeking to obtain support from the agency which makes the lesser demand for local contribution, thereby confusing the Congress as well as the tax payers who in the end pay the bill.

In conclusion, the writer recognizes that there remains much to be done to secure teamwork at the Federal level among the more than 40 Federal agencies that have an interest in some phase of water resources development. An article on this subject is in course of preparation by the writer.

RESOLVING CONFLICTING DEMANDS FOR WATER[a]

Discussion by J. Ernest Flack

J. ERNEST FLACK,[1] J. M. ASCE.—This interesting and valuable paper emphasizes one of the most difficult and perplexing problems in water resources planning and development—that of planning for potential uses of water where conflicting demands for the water exist. That cooperative planning for the waters of international streams is the exception rather than the rule can be illustrated by the major undeveloped river systems of the world. These rivers are usually international in character and conflicting demands for the use of their waters have left them largely undeveloped. The author has described some of these streams.

For the Colorado River, the author has pointed out that the terms of the Mexican Water Treaty covering this river were accepted as a compromise in the interests of international amity. Breitenstein(1) has expressed the view that engineering planning expedition also played a large part in the favorable action of at least five of the Colorado River Basin states. He stated that these states approved the Treaty terms in order that the water supply available for use in the United States could be known and so that the Bureau of Reclamation could be consistent in its position that the water supply available for use in each state must be known. Nevertheless the exact contribution which each state must make to the Mexican delivery requirement under ultimate conditions of development has not, yet, been agreed on.

The author also questions the quality requirements of future deliveries of water to Mexico. Bliss(2) has concluded that consumption of water by the Initial Phase operation of the Upper Colorado River Storage Participating Projects will have little practical effect upon the quality of water of the Colorado River below Glen Canyon Reservoir. His figures indicate that the Initial Phase would increase the average salt content from 0.73 tons per acre-foot to 0.85 tons per acre-foot, and that under ultimate depletion of 7.5 millions acre-feet per year in the Upper Basin, the salt content would increase to about 1.15 tons per acre-foot, ignoring certain modifying effects. This value is well within the "good to permissible" range. The same general conclusion has been given by Hinds(3) who concluded that the mineral content of the Colorado River under the most unfavorable future conditions would still be better than water actually diverted and used in the Lower Basin, before the construction of Hoover Dam.

The water quality will be further improved in passing through Lake Mead. The effect of reservoirs, in general, is to reduce the salts because of permanent deposition from solution. That the reservoir effect on salt concentration

a. Proc. Paper 1501, January, 1958, by Samuel B. Morris.

1. Asst. Prof., Dept. of Civ. Eng., Univ. of Colorado, Boulder, Colo.

does take place was seen in 1951 when the water imported to the South Coastal area of California increased in salinity and hardness over previous years.(4) This increase was because the reduced inflow to Lake Mead was more saline and harder and because the smaller holdover content of Lake Mead gave greater weight and effect to the more saline bottom storage. The reversal of the trend to a substantial decrease in average salinity and hardness of Lake Mead has been recently reported,(5) and is caused by the softer and less saline inflow and increased holdover storage due to the increased discharge of the Colorado River.

The author blames the Government for the shortages of water on the Colorado River by putting these waters on Upper Basin lands. The excess flows of the Colorado River that now waste into the sea are not, by compact, available for any but temporary use in the Lower Basin. The Government of the United States did not apportion the water. This was done by the Colorado River Compact and the Upper Colorado River Compact, signed by the interested states. The Government, through the Bureau of Reclamation, does cooperate in the planning and is responsible for the construction of facilities to use the greater part of the apportioned waters not now used. The cost and extent of these projects will generally require Federal financing and assistance in construction.

Planning the Upper Basin uses of Colorado River water requires a forecast of possible (not necessarily probable) future domestic and industrial use as well as irrigated agricultural use. The Hill Report(6) estimates a total average annual depletion of 300,000 acre-feet for the oil shale and other industries and for a population of 1,000,000 on the West Slope in Colorado. This same report gives the following average annual depletions of Colorado River water in Colorado available for future use.

Municipal and Industrial use	300,000 a.f./yr.
Irrigated Agriculture	800,000 "
Transmountain Diversions	300,000 "
Total	1,400,000 a.f./yr.

The report also gives 1,450,000 a.f/yr. as Colorado's share of the future possible depletions of the Colorado River. The difference between the future possible uses and the total available leaves 50,000 a.f./yr. surplus, on the average, to serve the Mexican Treaty.

The author has expressed some concern over the possible future need for domestic use of part of the 800,000 acre-feet listed above for irrigated agriculture. A summarization of the stream depletions of all of Colorado's participating projects under the Upper Colorado River Storage Act totals approximately 500,000 acre-feet, leaving some 300,000 acre-feet for later development. Person(7) has pointed out that even with the Lower Basin using all their allocated water there is more than sufficient water for the Upper Basin Initial Phase projects.

A study made by the writer(8) indicates that on the San Juan River in Colorado the total present and potential depletions are about 13% of the allocated Colorado depletion as determined by the Hill Report. This is substantially less than the 20% contribution of the San Juan River to the flow of the Colorado River at Lees Ferry. If this same general relationship holds throughout the Upper Basin then potential depletions by the Upper Basin irrigation projects will not make full use of the water allocated to the Upper Basin. It can be concluded that economic feasibility and the amount of

subsidies and not water availability will determine the extent of development of Upper Basin projects.

With regard to conflicts between municipal and irrigation use, it has generally been expressed that these are the highest uses of water in the arid regions. If expanding municipalities convert land use from irrigation to urban the consumptive use is actually reduced. This may be illustrated by values determined by the California Department of Water Resources.(9) This agency gives the estimated mean seasonal values of consumptive use of water on irrigated lands in the San Diego hydrographic unit as 2.0 feet of depth. Compared to the consumptive use of applied water on urban and suburban areas of 0.6 feet this shows a saving of 1.4 feet, assuming that full use can be made of return flow from the urban areas. Even if this cannot be done the total delivery to the urban areas is only 1.8 feet or 0.2 feet less than the consumptive use for irrigated lands.

However, as pointed out by the author, the unparalleled growth of the City of Los Angeles resulted in the acquisition of lands and water rights in the Owens Valley in order to insure a water supply for Los Angeles. This resulted in the 50,000 acres irrigated in 1910 in Owens Valley(9) being reduced to the present day virtual elimination of irrigated agriculture from the economy of the valley. If the present partial water supply could be made firm then it could be envisioned that a return to the former irrigated agriculture could result. This would require the importation of substantial quantities of water and such a scheme does not appear economically feasible. In fact, Los Angeles must continue to export water if no damage is to incur to the brine processing industry now located on the dry Owens Lake bed. While some agricultural development on favorable lands could utilize water presently wasted by phreatophytes the future of such an area appears to be in the development of recreation resources.

The conversion of irrigated lands to residential areas or other uses will usually make more water available elsewhere since the domestic consumptive use is smaller than irrigation consumptive use. Other problems arise, however, because of the loss of productive land, and because the water made available will probably not be used to the degree that it was when used to irrigate land due to hold orders on possible use for domestic purposes. Beneficiaries of return flow may have their flow cut off. In Utah, newspaper accounts reveal that the State wants the Bureau of Public Roads to change their criteria for the Interstate Highway System to permit the highways to skirt the valley floors so that valuable farm lands are not cut up or used for roadways.

Over-development, as far as available water resources are concerned, can happen in irrigated areas as well as in municipalities. And in the same manner that these cities must look to other sources for water so much the irrigated areas. The result of such over-appropriation of the limited water supply on the Eastern Slope in Colorado has resulted in two things: (1) the judicious use of all available water, and (2) the development of a large transmountain diversion project—the Colorado-Big Thompson.

Parshall(10) has shown that the use and re-use of return flow in north-central Colorado has resulted in 1 cfs serving about 434 acres of land, far more than the usual figure of 1 cfs for 80 acres. The recurrent water shortages in this same area resulted in the construction of works for the annual diversion of about 300,000 acre-feet of Colorado River water into the valleys of the Cache La Poudre, Big Thompson, and other Eastern Slope rivers. In order to obtain this water it was necessary to construct facilities to provide

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Transmountain Diversions	300,000 "
Total	1,400,000 a.f./yr.

The report also gives 1,450,000 a.f/yr. as Colorado's share of the future possible depletions of the Colorado River. The difference between the future possible uses and the total available leaves 50,000 a.f./yr. surplus, on the average, to serve the Mexican Treaty.

The author has expressed some concern over the possible future need for domestic use of part of the 800,000 acre-feet listed above for irrigated agriculture. A summarization of the stream depletions of all of Colorado's participating projects under the Upper Colorado River Storage Act totals approximately 500,000 acre-feet, leaving some 300,000 acre-feet for later development. Person(7) has pointed out that even with the Lower Basin using all their allocated water there is more than sufficient water for the Upper Basin Initial Phase projects.

A study made by the writer(8) indicates that on the San Juan River in Colorado the total present and potential depletions are about 13% of the allocated Colorado depletion as determined by the Hill Report. This is substantially less than the 20% contribution of the San Juan River to the flow of the Colorado River at Lees Ferry. If this same general relationship holds throughout the Upper Basin then potential depletions by the Upper Basin irrigation projects will not make full use of the water allocated to the Upper Basin. It can be concluded that economic feasibility and the amount of

subsidies and not water availability will determine the extent of development of Upper Basin projects.

With regard to conflicts between municipal and irrigation use, it has generally been expressed that these are the highest uses of water in the arid regions. If expanding municipalities convert land use from irrigation to urban the consumptive use is actually reduced. This may be illustrated by values determined by the California Department of Water Resources.(9) This agency gives the estimated mean seasonal values of consumptive use of water on irrigated lands in the San Diego hydrographic unit as 2.0 feet of depth. Compared to the consumptive use of applied water on urban and suburban areas of 0.6 feet this shows a saving of 1.4 feet, assuming that full use can be made of return flow from the urban areas. Even if this cannot be done the total delivery to the urban areas is only 1.8 feet or 0.2 feet less than the consumptive use for irrigated lands.

However, as pointed out by the author, the unparalleled growth of the City of Los Angeles resulted in the acquisition of lands and water rights in the Owens Valley in order to insure a water supply for Los Angeles. This resulted in the 50,000 acres irrigated in 1910 in Owens Valley(9) being reduced to the present day virtual elimination of irrigated agriculture from the economy of the valley. If the present partial water supply could be made firm then it could be envisioned that a return to the former irrigated agriculture could result. This would require the importation of substantial quantities of water and such a scheme does not appear economically feasible. In fact, Los Angeles must continue to export water if no damage is to incur to the brine processing industry now located on the dry Owens Lake bed. While some agricultural development on favorable lands could utilize water presently wasted by phreatophytes the future of such an area appears to be in the development of recreation resources.

The conversion of irrigated lands to residential areas or other uses will usually make more water available elsewhere since the domestic consumptive use is smaller than irrigation consumptive use. Other problems arise, however, because of the loss of productive land, and because the water made available will probably not be used to the degree that it was when used to irrigate land due to hold orders on possible use for domestic purposes. Beneficiaries of return flow may have their flow cut off. In Utah, newspaper accounts reveal that the State wants the Bureau of Public Roads to change their criteria for the Interstate Highway System to permit the highways to skirt the valley floors so that valuable farm lands are not cut up or used for roadways.

Over-development, as far as available water resources are concerned, can happen in irrigated areas as well as in municipalities. And in the same manner that these cities must look to other sources for water so much the irrigated areas. The result of such over-appropriation of the limited water supply on the Eastern Slope in Colorado has resulted in two things: (1) the judicious use of all available water, and (2) the development of a large transmountain diversion project—the Colorado-Big Thompson.

Parshall(10) has shown that the use and re-use of return flow in north-central Colorado has resulted in 1 cfs serving about 434 acres of land, far more than the usual figure of 1 cfs for 80 acres. The recurrent water shortages in this same area resulted in the construction of works for the annual diversion of about 300,000 acre-feet of Colorado River water into the valleys of the Cache La Poudre, Big Thompson, and other Eastern Slope rivers. In order to obtain this water it was necessary to construct facilities to provide

compensatory water on the West Slope. It is doubtful that early planning could have foreseen the difficulties for these two examples, i.e., the City of Los Angeles Aqueduct and the Colorado-Big Thompson Project, since irrigation in both the Owens Valley and the Platte Valley started in the 1860's.

Even in planning against conflicting uses variation can be found in the most optimum use of water. In general, the higher economic opportunity of domestic and municipal use is admitted. In the arid regions, however, the very establishment of municipalities and their consequent growth is dependent on irrigated agriculture.

> "Agriculture is, and probably always will be, the foundation of the civilization in the arid regions. Industries cannot be either established or maintained unless there is some assured balance with the production of raw materials on the farms and ranches. This is possible only by using water for irrigation."(11)

The planning and development of water resources must recognize the cultural and economic factors which have resulted in conflicting demands for water and resolve these conflicts by agreement and projects. With the rapidly increasing population and the necessity to feed more people, careful consideration must be given the conflicting demands of water use for human consumption and for crop consumption.

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METHODS OF COMPUTING CONSUMPTIVE USE OF WATER[a]

Discussion by Harry F. Blaney

HARRY F. BLANEY,[1] M. ASCE.—Mr. Criddle's paper presents an excellent summary of different methods developed by research engineers and scientists of computing consumptive use of water. It provides the practicing engineer with the basic data and methods required to estimate consumptive use in utilization of water investigations. In water-supply and irrigation investigations, engineers are called upon to make, within a limited times, estimates of probable past, present, and future evaporation and evapotranspiration losses from areas in river valleys. Sometimes, few long-period hydrologic records, except climatological data, are available.

For example: in 1948, the writer and the author were confronted with the problem of determining within several months time the average rate of consumptive use for the period 1914-45 in valley areas extending several thousand miles along the Upper Colorado River and its tributaries in the states of Arizona, Colorado, New Mexico, Utah and Wyoming.(1) Procedures developed in the Pecos River Joint Investigation(2,3) and other studies throughout the West were employed. Because of the limited measurements of consumptive use in the Upper Colorado River Basin, estimates of unit consumptive use by various agricultural crops and natural vegetation and evaporation from water surfaces, were based, primarily, on studies in other areas of the West, transferred to the Upper Colorado River Basin through relationships established, empirically, between measured consumptive use and climatological data by the application of the Blaney-Criddle formula, $U = KF$ = consumptive use in inches for any period.(4)

The consumptive use coefficients (K) for the more important irrigated crops grown in the Upper Colorado River area and native vegetation and evaporation are shown in Table 1. These coefficients were developed from actual measurements of consumptive use.

The results of this study were instrumental in the apportionment of consumptive use of water to the States of Arizona, Colorado, New Mexico, Utah and Wyoming under the Upper Colorado River Basin Compact which was approved by the legislatures of each of the signatory States and by the U. S. Congress early in 1949.

A recent method of computing consumptive use, which author did not describe, is the use of black and white atmometers developed by Dr. F. J. Veihmeyer of the University of California.(5) The results of this study indicate a high degree of correlation between the use of water by irrigated crops

a. Proc. Paper 1507, January, 1958, by Wayne D. Criddle.

1. Irrig. Engr., Western Soil and Water Management Research Branch, Soil and Water Conservation Research Div., Agri. Research Service, U. S. Dept. of Agri., Los Angeles, Calif.

Table 1 - Coefficients used in computing consumptive use of water in the Upper Colorado River Basin

Classification	Growing season or period	Consumptive use coefficient (K) 1/	
		Growing period:	Annual
IRRIGATED LAND			
Alfalfa	Frost-free period	0.85	
Alfalfa	Pre-frost free period	.70	
Grass, hay and pasture	Frost-free period	.75	
Grass, hay and pasture	Pre-frost free period	.60	
Beans and small grains	3 months	.75	
Corn and other annuals	4 months	.75	
Orchard (deciduous)	Frost-free period	.65	
INCIDENTAL AREAS			
Water surfaces 2/	Frost-free period	0.95	0.85
Native vegetation	Frost-free period		
Very dense 3/	Frost-free period	1.35	1.10
Dense 4/	Frost-free period	1.20	1.00
Medium 5/	Frost-free period	1.00	.90
Light 6/	Frost-free period	.80	.65
Sparse 7/	Frost-free period	(Precipitation only)	
Seeped areas 8/	Frost-free period	.90	.75

1/ $K = \frac{U}{F} = \frac{\text{Consumptive use}}{\text{Consumptive use factor}}$ = Consumptive use coefficient.

2/ Based on four-year record at Montrose, Colorado.

3/ Large cottonwood trees, willows and grass. Adequate moisture available from high water table (or ground water).

4/ Willows, tamarisk, or small cottonwood trees. Adequate moisture available from high water table (or ground water).

5/ Small willows or tamarisk. Moisture available from high water table (or ground water).

6/ Salt grass, brush and weeds. Moisture available from ground water.

7/ Sage brush, grass and weeds. Moisture available from precipitation only. (Rainfall during the growing season plus 50 percent of winter precipitation stored in the root zone, not to exceed 3 inches.)

8/ Moist areas caused by seepage from canals, over-irrigation, ground water, or poor drainage.

and the difference between black and white Livingston atmometer evaporation, especially during the summer months. The relationship is expressed by the formula U = SD = use of water in inches, where "S" is a coefficient for crops and "D" is the difference in evaporation between black and white Livingston atmometer. Table 2 gives the coefficients "S" for different crops based on records for months of May to September.

Table 2 - Coefficients in the Formula U = SD, and the Correlation Coefficients for Water Use by Various Crops and Difference in Evaporation for Black and White Atmometers (5).

Kind of Crop	Coefficient S	Correlation Coefficient r [a]
Alfalfa	0.0134	0.99
Walnuts	0.0135	0.97
Apricots	0.0120	0.95 [b]
Peaches	0.0110	0.98
Prunes	0.0108	0.98
Cotton	0.0105	0.97 [b]
Sugar Beets	0.0096	0.99
Grapes	0.0086	0.98
Tomatoes	0.0082	0.98
Artichokes	0.0073	0.98 [b]

[a] The correlation coefficients were determined from the formula derived for small samples.

[b] Values are from one year's record only. For the years of record for which the mean values are calculated for the other crops, see table 1.

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Table 3. - Comparisons of Measured Monthly Consumptive Use by Alfalfa and Computed Consumptive Use by Atmometer and Blaney-Criddle Methods.

Consumptive Use of Water by Alfalfa, Year 1937-38					
Month	Measured data (5) (u)	Atmometer Method (u) a/	Blaney-Criddle Method (4) (f) b/	(k) c/	(u)
	Inches	Inches			Inches
May	6.8	7.1	6.50	1.05	6.8
June	7.9	8.0	7.07	1.12	7.9
July	8.3	8.2	7.60	1.09	8.3
Aug.	7.1	7.1	6.93	1.02	7.1
Sept.	4.3	4.3	5.90	0.73	4.3
Total	34.4	34.7			34.4

a/ Computed by Atmometer equation U = SD = consumptive use inches.

b/ $f = \frac{t \times p}{100}$ = monthly use factor using monthly temperature (t) at Davis, Calif.

c/ Computed monthly coefficient $k = \frac{u}{f} = \frac{\text{consumptive use}}{\text{monthly use factor}}$ (in equation u = kf)

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USBR'S LOWER-COST CANAL LINING PROGRAM[a]

Discussion by Frederick L. Hotes

FREDERICK L. HOTES,[1] M. ASCE.—The leadership and contributions of the United States Bureau of Reclamation in connection with the development of lower-cost canal linings are recognized throughout the world. Certainly it is in this direction that some of the greatest improvements have been made, and can continue to be made, in irrigation engineering; for truly low-cost canal linings mean not only conservation of water and reduced drainage problems, but may also mean lower annual costs considering both initial costs and maintenance charges.

Another very important factor, particularly as regards secondary systems, is the conservation of land, and the ease and increased flexibility of farming operations that can be achieved by the use of concrete pipe distribution systems. The author has briefly mentioned the use of monolithically cast-in-place concrete pipe in this regard. A very similar type of pipe is the cast-in-place concrete pipe constructed in two parts. Both of these types of pipes are unreinforced. They have been used extensively for many years in California, particularly by the Turlock Irrigation District in the San Joaquin Valley. This District is reported to have successfully installed over 200 miles of two-part type pipe, with a saving of 0.6 of an acre of land per 1000 lineal feet of lateral, as compared to open ditches of the same capacity.[2]

Engineers not acquainted with these special types of pipes, should be aware of their relative economy. 1954 prices in the Turlock area were approximately as follows (for two-part type pipe):

Inside Diameter	Cost per lineal foot, including Excavation, Backfill and Levelling
30 in.	$1.60
36 in.	$2.00
42 in.	$2.90

The above prices reflect conditions where the contractors have had several years of experience in this type of work for the Turlock District. Many of these pipes have been in successful operation for several years.

In the opinion of the writer, the economy and advantages of such pipes, merit more consideration for their use in distribution systems than they have received in the past.

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a. Proc. Paper 1589, April, 1958, by R. J. Willson.

1. Water Conservation Engr., Development & Resources Corp., New York, N. Y. Stationed in Ahwaz, Iran.

2. Monolithic Concrete Pipe, Western Construction News, February 1946.

IRRIGATION IN NEW JERSEY[a]

Discussion by Frederick L. Hotes

FREDERICK L. HOTES,[1] M. ASCE.—This very interesting and informative article, about a relatively humid area where irrigation has now evidently been firmly established as a permanent part of the agricultural pattern, contains several facts and ideas that are of value also to those working in arid or semi-arid areas. It is particularly encouraging to note the worthwhile work on the utilization of brackish waters, and the fresh approach to the complex, but vitally human, problems of water rights.

There is one portion of the article, however, that, perhaps inadvertently, leaves an incorrect impression as regards the relative merits of sprinkler and surface methods of irrigation. In the section on "Irrigation Practices" (pp. 1591-3,4) it might be inferred from the statements contained therein referring to a California study, that surface irrigation in California is generally more expensive than sprinkler irrigation. In by far the greater majority of cases, the opposite is more correct. Surface irrigation methods are, in most irrigated areas of the world, still the more economical.

Many factors enter into an economical comparison of sprinkler and surface irrigation. The selection of the method to be used in any particular instance should be made on a careful evaluation of all of these factors, with a minimum of influence from either enthusiastic salesmanship or hidebound conservatism. In the case of New Jersey, it would appear that the relative advantage of sprinkler irrigation, is primarily due to the high cost of land preparation for surface irrigation in this particular region, as noted by the author. Another very important advantage might well be the relative simplicity of sprinkler irrigation, as opposed to surface irrigation, when introduced into an area where agriculture is already flourishing and has been long-established. Sprinkler irrigation, in these cases, would seem to blend best with the existing ecological regime, and the knowledge and habits of the local farmers.

It may well be that at some future date, improvements in sprinkler irrigation equipment and techniques may make it the only economical method to use in humid areas. To the writer's knowledge, this general rule has not yet been demonstrated, in spite of the overwhelming trend toward sprinkler irrigation in the eastern portion of the United States. There may still be areas in the humid east where surface irrigation is the better method.

a. Proc. Paper 1591, April, 1958, by Robert L. Hardman.

1. Water Conservation Engr., Development & Resources Corporation, New York, N. Y. Stationed in Ahwaz, Iran.

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THE IMPORTANCE OF HYDRAULICS OF SURFACE IRRIGATION[a]

Vaughn E. Hansen,[1] M. ASCE
(Proc. Paper 1788)

SUMMARY

Surface irrigation is a complex hydraulic phenomenon. The hydraulic elements involved in surface irrigation are listed and discussed. Relating these hydraulic elements is the key to efficient irrigation, good design, and a permanent agriculture.

INTRODUCTION

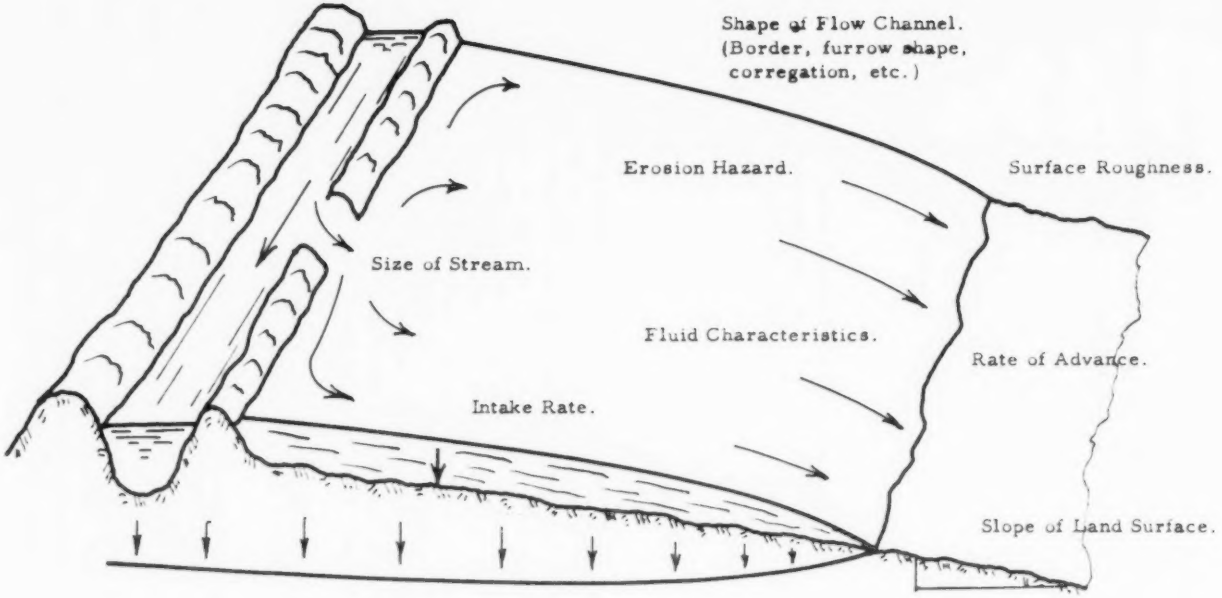
A general perspective of irrigation and its inherent problems are essential to seeing clearly need, scope, function, and importance of hydraulics in attacking our irrigation problems. The purpose of this paper will be to first outline the objective of irrigation and to point out some of the problems which automatically arise as soon as we attempt to irrigate. How these problems are related to hydraulics will be shown in general terms. The hydraulic variables involved in surface irrigation are not generally understood and the importance of these variables in surface irrigation are often overlooked. A technical discussion of these hydraulic relationships is beyond the scope of this paper. The purpose herein is to show that it is important to understand the hydraulics of surface irrigation if we are to develop a permanent irrigated agriculture.

Consideration will be given to the general problem of surface irrigation, sprinkler irrigation being a special case of the more complex surface irrigation analysis.

Note: Discussion open until February 1, 1959. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1788 is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. IR 3, September, 1958.

a. Presented at the First Intersociety Conference on Irrigation and Drainage, San Francisco, Calif., April 30, 1957.

1. Director, Eng. Experiment Station and Prof. of Civ. and Irrigation Eng., Utah State Univ., Logan, Utah.



HYDRAULICS OF IRRIGATION WATER APPLICATION

Schematic View of Border Irrigation Illustrating the Basic Variables Involved in the Hydraulics of Surface Irrigation

Irrigation Objectives and Problems

Objective: To distribute water over the land in such a way that it will enter the soil and be stored uniformly within the potential root zone.

It is impossible and impractical, except when using small basins, to accomplish fully this objective. As soon as we try to distribute the water uniformly, serious problems arise making it virtually impossible to uniformly store the water within the potential root zone. A number of problems immediately encountered in some degree whenever we attempt to irrigate are as follows:

(1) Obtaining uniform distribution of water over the surface.
(2) Obtaining uniform distribution of water under the surface.
(3) Reducing runoff from the soil surface.
(4) Reducing deep percolation.
(5) Reducing soil erosion.
(6) Obtaining a favorable salt balance.

These difficulties can be readily observed in almost any irrigated area—they result in poor irrigation. Either too little or too much water is applied, water is wasted, drainage problems are created, saline conditions develop, and excessive soil erosion occurs.

When the engineer attempts to solve this problem in planning a more efficient irrigation system, the following characteristics of the irrigation phenomenon are usually of importance:

(1) Intake rate
(2) Length of run
(3) Size of stream
(4) Slope of land
(5) Width of border, size of furrows, etc.
(6) Nature and magnitude of erosion

To assist in the evaluation of these variables, irrigation field trials have been designed by the Soil Conservation Service of the U. S. Department of Agriculture.[1] The technician will irrigate a trial area in the desired manner, observing and evaluating the intake rate, size of stream, slope, size, and shape of the flow area, and the tendency for erosion. From his observations recommendations will be made for the design or improvement of the irrigation system.

Importance of Hydraulics

The field-trial method developed by the Soil Conservation Service is useful in evaluating the effect of existing conditions upon the irrigation practice. The limitations of this procedure are that the answer applies only to the field being tested, and applies only to the conditions existing at the time of the test. Subsequent irrigation practice, tillage, crops, seasonal changes, climate, and other factors all have a profound effect upon the behavior of the water as it moves above, into, and through the soil. Only very limited guides are available for extrapolating existing conditions into the future to predict subsequent results. Hence, field measurements essentially apply only to present conditions on the field being tested and cannot safely be used as an index to future

conditions even on the same field. Extrapolation to other fields is very difficult and hazardous. The Soil Conservation Service technicians fully realize this limitation and are making commendable advancements in defining principals which can be used to predict future conditions.

A sound but practical mathematical expression is needed to describe the hydraulic features of the flow. After such a relation has been developed, the results of field trials will be more meaningful and can be used more satisfactorily to predict future conditions or conditions existing on adjacent lands.

Fundamental Hydraulic Characteristics of the Flow

Before the component aspects of the flow can be related, a clear physical picture of the phenomena is needed. To begin the analysis, refer to Fig. 1 showing a schematic view of border irrigation. The basic variables involved in the hydraulics of surface irrigation are as follows:

(1) Rate of application of the water.
(2) Intake rate, rate of movement of the water into the soil.
(3) Rate of advance of water over the land surface.
(4) Roughness of the surface.
(5) Shape of the flow channel; whether it is a border, a corrugation, or a given shaped furrow.
(6) Slope of the land.
(7) Erosion hazard.
(8) Fluid characteristics of the water, affected primarily by temperature.

Some of these quantities can be expressed in terms of other variables. For example, the intake rate can be replaced by the rate of advance of the wetting front down through the soil and the degree of saturation of the soil. Likewise, the location on the soil surface of the advancing water front and the shape of the moisture penetration curve will replace the intake rate. Also, the depth of flow and the shape of the water surface will replace the rate of advance. And temperature of water is a good index to fluid characteristics of viscosity and density.

The following section defines further the meaning and importance of each of these variables and discusses briefly the present status of each.

Rate of Application

The rate at which water is applied to the field is one of the basic variables governing good irrigation design. Methods of measuring the amount of water delivered to the field are available. Weirs, Parshall flumes, and meters are in general use. Improvement is needed, but the present status of water measurement is not a serious restriction to the general problem of the hydraulics of surface irrigation. The principle need is for more measurements of applied water.

Intake Rate

One of the most complex aspects of the hydraulics of surface irrigation is the variable rate at which water enters the soil. Not only does it vary with soil type but with tillage, surface debris, vegetative cover, season, climate, etc. Characteristics of surface flow are greatly influenced by the intake rate.

Tremendous sums of money have been spent collecting data on the intake rate. Considerable effort and money has subsequently been spent trying to analyze the data. Very little has ever been published. Too many variables were involved, being allowed to vary at random, often unmeasured, and frequently ignored. The answer to this component of the general irrigation problem lies in the careful analysis and in controlled experimentation wherein the variables involved are known, the nature of their influence predicted, and these variables either eliminated, held constant, or measured. Only thereby will order come out of the chaos that now surrounds this important component of irrigation.

The fundamental nature of the intake phenomena has been discussed by a number of capable scientists.[2,3,4,5,6,7] The author has summarized these results and drawn conclusions from analysis of the data showing the engineering significance of the fundamental relationships.[8] Additional controlled research is needed to verify the proposed relationships and to develop techniques that can easily be used in the field to obtain data capable of interpretation.

Considerable attention has been devoted to developing field methods of obtaining intake data. An excellent summary has been recently published by the U. S. Dept. of Agriculture.[9]

Another noteworthy step forward has been made by the American Society of Agricultural Engineers through its soil and water division. The irrigation group of this division has organized a committee on standards for measuring intake rates of soils for irrigation system design. Such coordinating activity by the professional societies will do much to stimulate and promote progress in the intake field.

Rate of Advance

The rate that water moves over the surface is of basic importance and is one of the most important characteristics of surface irrigation. Direct measurements can be made and indeed many measurements have been made. Nevertheless, their interpretation is difficult, if not impossible, until the hydraulics of the flow are evaluated.

Surface Roughness

Roughness of the surface over which the water flows relates to both the soil surface and the vegetation within the flow channel. For example, border irrigation of alfalfa is influenced by the alfalfa crowns and stems as well as by the characteristics of the soil surface. The roughness characteristic of a grassed surface-drainage channel will depend upon the velocity of the flow. If the water moves through the vegetation, the roughness will be one value; whereas if the velocity is fast enough to bend over the vegetation, causing the water to flow over the surface of the vegetation, the roughness characteristic will change.

Excellent progress has been made in defining the roughness of pipe. These developments are well outlined in most fluid mechanics texts. Several semi-empirical flow formulas have been developed for open channels. In these developments the roughness has not been nearly as completely defined as in the case of pipe flow.

The major need today is for the evaluation of a coefficient of roughness for open channel flow. The coefficient needs to be evaluated in terms of the

relative roughness and the flow characteristics in a manner similar to the analysis of the frictional factor in pipe flow. Some excellent progress has been made in this direction,[10,11,12] more is needed.

Shape of the Flow Channel

The characteristics of any fluid flow are modified by the shape of the flow channel. This effect is complex for furrow irrigation and is complicated by the changes which occur in the cross-section of the channel with time.

The concept of hydraulic radius, the ratio of cross-sectional area to wetted perimeter, is very useful in characterizing shape. However, another shape factor may possibly be more useful. Careful attention needs to be given to this variable.

Slope of the Land

The slope of the land has a major influence upon the rate that water moves over the surface. The existing slope can be easily measured and the way in which slope influences the flow is common knowledge. This variable, like the rate of application, does not present a serious deterent to progress. However, with extensive land leveling becoming common, the desirable slope is becoming increasingly important. Flat slopes are popular in the western portion of the states of Texas, Oklahoma, Kansas and Nebraska. Also the desirability of variable slopes is being given considerable thought. Defining the general hydraulic relationship is essential before the needed answers regarding the desirable slope can be obtained.

Erosion Hazard

Extensive generalities have been spoken and written regarding erosion. Despite the fact that enormous sums of money have been allocated to "control erosion," essentially no practical measure of erosion hazard has been developed. Most of the studies of erosion have consisted of measuring the amount of erosion or devising ways of reducing erosion. Such objectives and efforts are of course necessary and commendable. However, little real progress will be made until a basic measure of erosion hazard has been developed. Specific criterion must be formulated to replace the generalities of the past. Today erosion hazard is generally spoken of in terms of adjectives such as moderate, serious, slight, etc.

Herein lies a fruitful field for hydraulic research. The more comprehensive science of fluid mechanics can be used to probe for answers which will apply to both water and air, involving thereby both water and wind erosion aspects. Both types of erosion are fundamentally the same.

The size of the stream and the slope must be adjusted to produce minimum erosion. Better irrigation design will result when the erosion hazard can be expressed quantitatively.

Fluid Characteristics

Temperature is the principle factor affecting the fluid properties of viscosity and density. Viscosity in turn directly affects the resistance to flow. For instance, a temperature change from 40° F. to 80° F. decreases the viscosity of water by 50%. Hence, the fluid properties cannot be ignored, and indeed need not be ignored because the nature of their influence upon the hydraulic phenomenon is known.

Hydraulics of Surface Irrigation

The general relationship defining the hydraulics of surface irrigation is no stronger than its component parts. These components have been discussed and the needs of each and the present status of understanding of each have been briefly outlined in general terms.

The problem now is to combine these components into a useful relationship. This is not easy because the hydraulics of surface irrigation contains all of the complexity of unsteady open-channel flow plus the complication of a variable inflow into the soil. Analysis are generally based upon the fact that the amount of water that has entered the field must be equal to the water on the surface plus the water that has entered the soil. Many approaches can be made, but the same basic concept still applies. Warren A. Hall at the University of California has published one of the more recent analyses of the hydraulics of surface irrigation.(13) Current studies are also underway at the State College of Washington and the Utah State University to further analyze the general phenomena.

A significant step forward was made when the American Society of Agricultural Engineers, through the Soil and Water Division, set up a committee within the irrigation division to study the hydraulics of surface irrigation. This action represents the first time that united, coordinated action has been taken to solve the problem of the hydraulics of surface irrigation. This committee is cooperating closely with the committee on intake measurements. It is envisioned that other technical committees will soon be organized by the professional societies to develop the other component phases which have been outlined herein.

Significant progress in defining the hydraulics of irrigation water application is inseparably connected to the degree with which the investigator understands and uses the fundamental physical aspects of the flow.

The variables must be quantitatively defined. Cooperative effort is essential to combining the variables into an effective relationship that can be used to design and operate efficient irrigation systems.

Until we understand the hydraulics of irrigation water application, we have little hope of making our agriculture permanent.

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PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1449 is identified as 1449 (HY 6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1957.

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c. Discussion of several papers, grouped by divisions.

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